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FLORIDA SCIENTIST

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Academy Symposium

SOLAR ENERGY

BRUCE NIMMO, *Chairman*

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THE 1976 Academy Symposium topic, *Solar Energy*, is indeed a timely one for the State of Florida and the nation as a whole. The crisis of energy availability persists, with many claiming that the truly difficult problems will be facing us in the near future. Solar energy, outstanding in extent and environmental acceptability, rises to the fore in any discussion of the energy dilemma as surely as the sun rises each morning.

Summary papers were presented at the symposium covering the historical development and present state of the solar industry, the importance of equipment testing and standards, the activities of the internationally known Solar Energy Laboratory of the University of Florida, the role and scope of the newly formed Florida Solar Energy Center, and finally a survey of projects under way at the Georgia Institute of Technology and their relation to major solar research and development projects around the world.

Hopefully, the exchange of information, the bringing together and summarizing of the literature and the opportunity for discussion will help bring the date for large scale utilization of solar energy a little closer for the State of Florida, the United States and the world.

TESTING OF FLAT PLATE SOLAR COLLECTORS AND SOLAR HOT WATER SYSTEMS

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ABSTRACT: *The introduction to the marketplace of solar equipment which does not meet performance expectations can have a serious detrimental effect on the industry and solar energy utilization in general. The equipment which industry produces must be efficient and well constructed. The best method of assuring that this will be the case is to have available a well thought out and executed solar equipment testing program. This paper reviews some flat plate collector and solar water heater testing literature and describes programs presently in existence. The theoretical basis for flat plate collector thermal performance criteria is discussed as are collector diagnostic testing techniques.*

AN ISSUE of considerable interest and importance to both consumers and manufacturers of solar equipment is the testing of solar components and systems. The emerging solar industry in the State of Florida, as well as in the rest of the country, suffers from a lack of uniform, definitive, acceptable procedures for such testing. As a result, shoddy or inoperative equipment of poor materials, design, or both, has found its way to the marketplace (Schwartzman, 1975).

The equipment which the industry produces must be efficient and well constructed, it must be durable and it must perform the job for which it was purchased. The user of the equipment must be able to specify the performance, both thermally and structurally, in a meaningful manner so that he will know after the equipment has been installed what he can expect of it.

If a set of standard test criteria is not developed, there is great potential for user disappointment with consequent destruction of trust and confidence. The result, of course, is unfavorable impact on current and future markets and serious delay in reaching the date when solar energy can make a meaningful contribution to the state and national energy budgets. Legislation is being developed for consideration by the Florida State Legislature to ensure that proper testing capability will be available in the state (Yarosh, personal communication).

The discussion of collector testing which follows is limited to the flat plate collector, the single most common solar device for both past and present applications.

COMPONENT AND SYSTEM TEST PROCEDURES PRIOR TO 1974—Development of a rational and useful solar collector test procedure requires familiarity with the analytical models which have been developed to enhance our understanding and predict the performance of such collectors. Two classic works which present flat plate collector analytical models are those of Hottel and Woertz (1942) and Hottel and Whillier (1958). These authors have applied basic techniques of thermal analysis to predict the amount of useful heat which can be collected using a "conventional" flat plate or "deck" beneath a transparent cover with the under-

side of the unit insulated to reduce downward heat loss. The useful heat gain is interpreted to mean the energy increase of the collector fluid as it passes through the collector

The expression for the collector fluid energy gain may be expressed in terms of collector parameters as

$$\text{Collector energy gain rate} = \text{Fluid flow rate} \times \text{Specific heat of fluid} \times \text{Inlet to Outlet Temperature Rise of fluid}$$

By measuring the individual items on the right hand side of this equation it is possible to calculate the useful energy gain. The collector heat gain rate may also be expressed as

$$\text{Collector energy gain rate} = \text{Solar irradiation rate} - \text{Solar radiation reflected from glazing to sky} - \text{Heat losses from collector}$$

In working equation format, these relationships become

$$q_u/A = \dot{m} c_p (T_{f,o} - T_{f,i}) \quad (1)$$

$$q_u/A = F_R [I(\tau\alpha)_e - U_L(T_{f,i} - T_a)] \quad (2)$$

where

q_u/A = rate of useful energy collection per unit collector area

F_R = heat removal factor which accounts for the fact that the energy losses are based on the difference between fluid inlet and ambient temperature instead of average plate temperature and ambient

I = total incident solar radiation

$(\tau\alpha)_e$ = effective transmittance (τ) and absorptance (α) product of the cover plate (s) and absorber surface combination

U_L = overall collector heat loss coefficient

T_a = ambient air temperature

$T_{f,i}$ = fluid inlet temperature

$T_{f,o}$ = fluid outlet temperature

If one divides both sides of the second equation above by I , the total incident radiation, a useful and commonly used collector efficiency, η , results.

$$\eta = \frac{q_u/A}{I} = F_R \left[\frac{(\tau\alpha)_e - U_L(T_{f,i} - T_a)}{I} \right] \quad (3)$$

Collector testing generally aims toward determining either the useful heat pickup or the collector efficiency.

Two early suggestions for standard experimental tests of flat plate collector solar water heaters were by Robinson and Stotter (1959) and Whillier and Richards (1961). The first paper discusses four parameters which it is suggested should be determined for performance ratings:

- 1) Thermal efficiency of the collector.
- 2) Aerial efficiency of the collector to reveal efficiency of space utilization (calculated as $A_{\text{active}}/A_{\text{total}}$).
- 3) Orientation efficiency determined from the angle between the incoming rays and a perpendicular to the collector (a moveable collector which continuously "faced" the sun would have an orientation efficiency of one).
- 4) Heat Storage Coefficient which reflects the overall heat transfer loss coefficient from the tank.

The paper by Whillier and Richards made a strong plea for international adoption of a standard test procedure for rating the performance of solar flat plate collectors on an instantaneous efficiency basis. The carefully controlled testing technique called for appears to have had considerable influence on the National Bureau of Standards test procedure (Hill and Kusuda, 1974). Whillier and Richards make the suggestion that $(\tau\alpha)_e$ and U_L can be determined from the instantaneous efficiency data. A description is given of the standard test apparatus which was set up as part of the basic facilities of the South African Council for Scientific and Industrial Research in Pretoria.

Numerous experimental test results for both collectors and solar water heater systems were reported in the literature during the 1950's, 1960's, and early 1970's with widely varying levels of sophistication in the experimental work. The works of Khanna (1968), Czarnecki (1958) and Whillier and Saluja (1965) are representative of the tests performed. Khanna and Czarnecki were concerned with total water heater systems (the former under actual "in use" conditions in India, the latter under simulated conditions in Australia). Khanna's paper lacks numerical or graphical results for the test conducted with corrugated galvanized sheet collectors. These collectors had life times of 2-4 yr depending upon the headers used. Czarnecki found that for the field trials in Australia the mean yearly contribution of solar energy to the hot water supply ranged from 61% to 81%. Whillier and Saluja placed greater emphasis on the solar collector itself, examining not only the details of the collector components but also discussing briefly diagnostic analysis of collector performance including bond conductance and selective surface degradation. They showed that weathering can have serious detrimental effects on certain selective surfaces.

Doron (1965), in a brief technical note has described two test methods (isothermal and varying temperature) used in the National Physical Laboratory of Israel in the early sixties. He points out that there are two possible operation modes for collectors; the "boiling" mode when the collector is essentially isothermal and the "heating" mode when the collector fluid enters at one temperature and exits at a higher temperature. Of course, in large collector arrays each collector may operate with only a small temperature rise and thus be well modeled by the "boiling" mode even though, in fact, no phase change takes place.

The Standards Institution of Israel (1966) established and published (S.I. 609) a standard for solar water heater test methods which led to collector efficiency, determination of the hot water output of the water heater, and system efficiency.

Nevins (1974) has described a variety of approaches used in Australia for testing solar collectors. These include simple comparative testing against a "standard" unit, detailed testing to determine collector loss coefficients and radiation absorption coefficient¹, and total system performance tests.

The results of a series of 3 wk solar hot water system tests, under a variety of simulated practical domestic conditions was described by Chinnery (1971).

RECENT SOLAR TEST PROCEDURE DEVELOPMENTS—A number of testing procedures were discussed at the National Science Foundation Workshop on Solar Collectors for Heating and Cooling of Buildings held in 1974. Lior (1974) proposed a daily heat capacity rating in lieu of efficiency tests in order to provide an operationally meaningful criterion for the customer. It indicates the effective quantity of heat collected during one day of each month for which solar collection is needed, at the general locality at which the collector is to be used.

The National Bureau of Standards (NBS) recommended test procedures, as developed by Hilland Kusuda (1974) and discussed by Hill (1975), lead to obtaining the efficiency of the collector under "steady state" conditions. Since the tests are specified for performance under real sunlight conditions they are in fact "quasi steady". The series of tests which are run at different temperature levels consist of determining the average collector efficiency for 15 min periods by measuring the flow rate through the collector and the temperature rise across the collector. For each test period constraints are given for cloud cover, ambient temperature variation, minimum insolation rate, incident angle between sun and a normal to the collector and instrumentation error levels. Kelly and Hill (1974) have presented test procedures which were developed at NBS for testing of thermal storage devices. These tests are designed to determine the heat loss factor for the unit and the response to step increases and decreases in the entering fluid temperature. An excellent review of the background for the NBS work is presented in Hill et al. (1976).

Lee (1974) prefers the calorimetric test method which avoids some of the difficulties and instrumentation costs experienced with the mass flow-temperature rise across the collector technique described by Hill above. The calorimetric procedure is based on a closed system in which the heat from the collector is stored in a large volume of well mixed water and the time rate of change of the temperature in the tank is measured to determine the energy rate pickup of the collector. The primary operational advantage of the technique is that only one variable need be monitored, the storage tank temperature, as opposed to, say, the NBS technique which requires measurement of flow and temperature. A potential drawback to the calorimeter approach is that one never achieves a steady state for fluid temperature. A result of this is, of course, that the thermal capacitance of the collector must be taken into account in the data reduction.

Simon (1974) has described a program carried out at the NASA Lewis Research Center for testing of collectors under conditions of simulated solar radiation. The advantage of the indoor solar simulator approach is that true steady

¹Equivalent to $(\tau\alpha)$, in equation 2.

state is achieved under controlled conditions of environment. The drawbacks are expense and potential mismatch between the true and simulated solar spectrum. The latter is particularly important in the case of so-called selective surfaces where performance is spectrally dependent. Results indicate the NASA-Lewis simulator has good spectral qualities and the indoor data are well correlated with those taken outdoors.

Two system-oriented mobile test facilities have been described in the literature. The Honeywell (1974) transportable solar laboratory was designed and built primarily as a means of evaluating "on board" solar heating and cooling systems under various climatic conditions. It also served as a traveling demonstration unit to acquaint the public with solar systems and capabilities. Nimmo and Larsen (1976) have described the design and development of a mobile solar testing and recording system to be used in the monitoring of "in use" solar hot water systems in the State of Florida. The design calls for capabilities of making appropriate measurements on both the older thermosyphon units and the newer pumped systems.

Most of the above material related to thermal performances. There are, of course, numerous other criteria (structural, safety, durability/reliability, maintainability) which must be considered in collector specification. A document which addresses itself to many of these other aspects is the NBS report "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings" (NBS, 1975).

Finally, mention should be made of the fact that commercial collector test facilities have been established at a few locations in the country and that a number of collector manufacturers have taken advantage of the services offered.

From this summary of testing activities, it is apparent that the large number of thermal performance tests reported in the literature may be grouped as shown in Table I. Although other related components such as auxiliary energy supplier, control devices and energy transport machinery might be added to the component list, these devices typically are common in conventional heating, ventilating and air conditioning design work and have been subjected in many instances to the tests of time and large scale usage.

TABLE I. Thermal performance testing of solar components and systems.

Component	System
-Collectors	-No load tests
-Test type: flow- ΔT or calorimetric solar or solar simulator	-Simulated load
-Purpose: Thermal system design or collector diagnostic	- <i>In situ</i> test with actual loads
-Storage	
-Loss coefficient	
-Transient response	

If a collector test is being performed to obtain information needed to fulfill a thermal performance specification² which has been written for a given system, then the amount of useful heat output or the collector efficiency as a function of environmental conditions would generally be satisfactory. If, on the other hand, the test is being performed to obtain information for a prescriptive specification or if the test is conducted as part of an R and D program on collector design, the greater detail is usually required in the conduct of the tests and presentation of report data. The National Bureau of Standards uses a modified form of equation 2 which is useful in obtaining diagnostic information from collector tests. By basing the energy losses from the collector on the difference between the average fluid temperature and the ambient temperature the following expression results.

$$\eta = \frac{F'(\tau\alpha)_e - F'U_L \frac{(T_{f,i} + T_{f,e}) - T_a}{2}}{I}$$

$$= F'(\tau\alpha)_e - F'U_L \Delta T/I$$

Streed (1975) has pointed out that by plotting the measured efficiency as a function of $\Delta T/I$ for a range of exposure condition, the collector performance can be characterized as shown in Figure 1. The y axis intercept is related to an experimental value of $(\tau\alpha)_e$ and the slope related to an experimental value of U_L .³ Figure 1 (Simon, 1973) suggests a linear relationship between η and $\Delta T/I$.

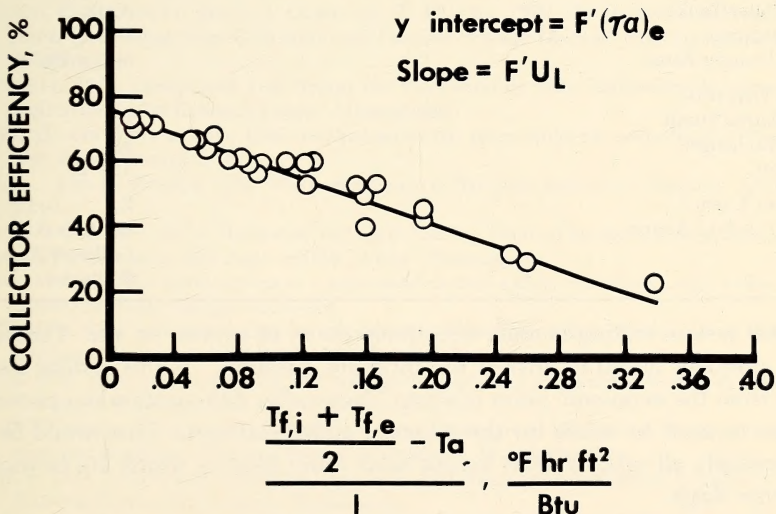


Fig. 1. Efficiency for a flat plate collector using water as the transfer fluid (Simon, 1973).

²The phrases performance specification and prescriptive specification have the following connotation. A performance specification describes the results to be achieved, such as BTU's of heat to be provided, a prescriptive specification describes the means to achieve desired results such as use of antireflective coatings (Hartman, 1974).

³ F' , which is the ratio of actual useful energy collected to the useful energy collected if the entire collector surface were at the average fluid temperature, is termed the collector efficiency factor. F' may be determined analytically for several common flat plate collector designs (Whillier, 1966).

However, it is recognized that in reality U_L is not a constant but rather a function of the collector and ambient temperatures. In addition, the product $(\tau\alpha)_e$ varies with the incident angle to the collector. (A variation of about 4% can be expected from 0 to 30 degrees). For common flat plate collector designs, the non-linearity of the curve will tend to show up at higher operating temperatures.

Streed (1975) has presented information on the interrelation between subsystems (components) and systems. He points out that tests covering most aspects of the performance attributes are required to fully identify the subsystem characteristics for the system designer to investigate their usefulness in the various functional applications. Streed has suggested the listing shown in Table 2 as representing some of the more significant system design requirements and pertinent sub-system test parameters.

TABLE 2. Relationship between subsystem and system performance.

System Design Requirements	Subsystem Test
ENERGY COLLECTION	
Effective Absorptance	τ_e
Heat Removal Factor	F_R
Loss Coefficient	$U_{L,k,t}$
Thermal Response	$(C_p)_c$
Efficiency vs. T & I	$\frac{\dot{m} C_p (\Delta T)}{I}$
ENERGY STORAGE	
Storage Tank	$(C_p)_s$
Hot Water Tank	$(C_p)_{HW}$
Stratification	T/d
Heat Transfer Rates	$\dot{m} C_p (T)t$
ENERGY TRANSFER	
Circulation Pump	P_e
Heat Exchanger	η_{he}
Control	$T_a > T_s$
AUXILIARY ENERGY	E_w
COLLECTOR TILT ANGLE	Latitude & Collector Angular Response

Total system testing is most effectively done, of course, on site. The on site test is uniquely suited to answer the ultimate question, "Is this system a sound choice from the economic point of view." Naturally, if the system is a prototype, allowances must be made for the inherent additional costs. This would be true for essentially all solar systems except solar water heaters which are beyond the prototype stage.

Two major efforts are presently under way by technical societies in the United States to assist in evolving standards for solar testing and cooling. The first is the work of the American Society for Testing and Materials (ASTM) carried out under subcommittee E21.10 Solar Energy Utilization. This work was instituted at a meeting held in Philadelphia in October, 1975. Several working groups have been established in the areas of materials and thermal performance.

Two special subcommittees have been appointed by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE). The standards work for thermal testing of collectors is being carried out under subcommittee 93-P and the standards for solar thermal energy storage are being studied by subcommittee 94-P. A report will be made to the ASHRAE standards committee in mid 1976. There appears to be a feeling that ASHRAE's responsibility should be limited to thermal testing of collectors while ASTM should have responsibility for durability and reliability of materials. The latter should include the behavior of the collector under "stagnation", or no flow conditions.

It is clear that the emerging solar industry as well as the emerging solar marketplace is urgently in need of standards and that the professional-technical societies and the federal government are moving to meet the need. Meanwhile, the potential solar customer should abide by all of the conventional wisdom required when one associates with a new product.

LITERATURE CITED

- CHINNERY, D. 1971. Solar water heating in South Africa. CSIR (Pretoria) Res. Rept. 248:8-24.
- CZARNECKI, J. 1958. Performance of experimental solar water heaters in Australia. *Solar Energy* 2:2-6.
- DORON, B. 1965. Testing of solar collectors. *Solar Energy* 9:103-104.
- HILL, J. 1975. Laboratory based activities in solar energy at the National Bureau of Standards. *ASTM Standardization News* 3:20-38.
- _____, AND T. KUSUDA. 1974. Method of Testing for Rating Solar Collectors Based on Thermal Performance. NBS Rept. NBSIR 74-635. Washington.
- _____, E. STREED, G. KELLY, J. GEIST, AND T. KUSUDA. 1976. Development of Proposed Standards for Testing Solar Collectors and Thermal Storage Devices. NBS Technical Note 899. Washington.
- HONEYWELL. 1974. Design and Test Report for Transportable Solar Laboratory Program. Honeywell Systems and Research Center. Minneapolis.
- HOTTEL, H. AND A. WHILLIER. 1958. Evaluation of flat plate collector performance. *Trans. Conf. Use of Solar Energy* 2:74.
- _____, AND B. WOERTZ. 1942. The performance of flat plate solar heat collectors. *ASME Trans.* 64:91.
- KELLY, G. AND J. HILL. 1974. Method of Testing for Rating Thermal Storage Devices Based on Thermal Performance. NBS Rept. NBSIR 74-634. Washington.
- KHANNA, M. 1968. The development of a solar water heater and its field trials under Indian tropical conditions. *Solar Energy* 12:255-261.
- LEE, D. 1974. Solar collector testing by calorimetry. Workshop on Solar Collectors of Heating and Cooling of Buildings. NSF-RANN 75-019:373-379.
- LIOR, N. 1974. Solar collector testing and standards. Workshop on Solar Collectors for Heating and Cooling of Buildings. NSF-RANN 75-019:349-358.
- NBS. 1975. Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings. National Bureau of Standards. Washington.
- NEVINS, R. 1974. CSIRO and Australian Experience in Testing Solar Collectors. A report to the U. S. National Bureau of Standards. Washington.
- NIMMO, B. AND R. LARSEN. 1976. Development of a mobile solar testing recording (STAR) System. *Proc. COMPLES Internat. Congr. Heliotechnique and Development*. Dhahran, Saudi Arabia, 1975: *in press*.
- ROBINSON, N. AND A. STOTTER. 1959. A proposed standard test code for the determination of the efficiency of solar water heaters of the flat collector type. *Solar Energy* 3:30-33.
- SCHWARTZMAN, R. 1975. Buyers "Heated" by Solar Unit. *Today Newspaper* April 28:10c.
- SIMON, F. 1974. Status of the NASA-Lewis flat-plate collector tests with a solar simulator. Workshop on Solar Collectors for Heating and Cooling of Buildings. NSF-RANN 78019:391-400.

- _____, AND P. HARLAMENT. 1973. Flat Plate Collector Performance Evaluation: The Case for a Solar Simulator Approach. NASA TM x-71427.
- STANDARDS INSTITUTION OF ISRAEL. 1977. Solar Water Heaters: Test Methods. SI609. Tel Aviv.
- STREED, E. 1975. The Relationships Between Tests on Components Separately and Tests on Performance of Solar Total Systems on Installations. Presented at the Conference on Standards for Solar Heating and Cooling, ASTM Headquarters. Philadelphia. October, 1975.
- WHILLIER, A. 1966. Low Temperature Engineering Application of Solar Energy. American Society of Heating, Refrigerating and Air Conditioning Engineers Inc. Chapter III.
- _____, AND S. RICHARDS. 1961. A standard test for solar water heaters. Proc. Conf. New Sources of Energy, Rome. Paper 5-97:111-113.
- _____, AND G. SALUJA. 1965. The thermal performance of solar water heaters. Solar Energy 9:21-26.

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Academy Symposium

PRACTICAL APPLICATION OF SOLAR ENERGY IN FLORIDA¹

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ABSTRACT: Promotion of cheap electricity and gas for mass-produced water heaters in the post World War II era led to the demise of the solar energy industry in Florida. The recent OPEC oil crisis precipitated renewed interest in solar energy for many uses. Solar water heaters are a mainstay for domestic users and construction materials, design parameters and designs are provided with notice of limitations of each type. Flat plate collectors have advantages over concentrating collectors for domestic use but are more limited in applications where temperatures more than 180°F are required. Beyond domestic water heating, solar energy can be stored for cooking or for heating and cooling a house but these uses are not yet cost-competitive with fossil fuels. Recovery of potable water by solar stills has been important in the past and is re-emerging with some urgency as population pressure creates increasing demands on available supplies. Entry of new disciplines into consideration of solar energy holds promise for expanded exploitation of our only continuously renewed natural resource—the sun.

THE past two years have seen the re-emergence of a fledgling solar industry in Florida. Companies large and small are vying for an elusive and ill-defined market for solar hardware. Some of them manufacture components, some total solar systems.

In some ways this activity conjures up visions of times past, for during the first half of this century a small solar industry enjoyed healthy development in Florida. For reasons to be discussed subsequently, that industry faltered during the 1960's and by 1970 the last vestiges of it had all but disappeared. But in other ways, the current re-emergence bears no resemblance to the past, for the reasons which have led to renewed activity in solar manufacturing, research and development are broader in scope and more persuasive in nature than the pressures which led to the solar activities of 1900 to 1960.

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To place current interest in perspective, it may be well to trace the rise and fall of previous solar activities in Florida which reached their peak in the 1950's.

HISTORY—Inland Florida of the early 1900's was largely rural and agricultural. The road system, until well into the 1920's, was only partially passable much of the year because of seasonal inundation of the many and broad flood plains throughout the state. Rural electrification was largely limited to the rail and navigable river corridors until the Florida land boom of 1925-27. Natural gas was not natural to most of Florida until Florida Gas installed a major gas distribution network in the 1960's.

By the 1920's plumbing was moved indoors, and it was natural that the old barber shop signs which read "Bath—10¢ (first water—20¢)" would begin to disappear. "Hot water in every room" appeared on billboards advertising Florida accommodations and it became fashionable to bathe more often than once a week. These changes in social customs required a source of low temperature energy and Florida's citizens had more sunshine than money available to them in those days.

Early Patents: A patent peripheral to the basic principle involving the transparency of glass to the solar spectrum and its opacity to long wave length heat radiation was issued to D. Rice in 1867 (U. S. patent no. 68459). In 1889, Charles Davis of Pasadena, California, "invented certain new and useful improvements in solar water heaters," according to records in the U. S. Patent Office. Many other patents covering solar devices were issued between then and World War II. These early patents included:

NUMBER ²	DATE	PATENTEE AND ADDRESS
966,070*	Aug. 2, 1910	Wm. J. Bailey, Monrovia, Calif.
1,003,514	Sept. 19, 1911	L. L. Roundtree, Cotton, Calif.
1,014,972	Jan. 16, 1912	T. F. Nichols, Bay, Ariz.
1,042,418	Oct. 29, 1912	A. H. Evans, Freeport, Ill.
1,056,861*	Mar. 25, 1913	T. W. Walker, Monrovia, Calif.
1,074,219	Sept. 30, 1913	F. A. Skiff, Pakta, Mass.
1,093,925	Apr. 21, 1914	H. L. Foresman, San Dimas, Calif.
1,242,511*	Oct. 9, 1917	Wm. J. Bailey, Monrovia, Calif.
1,250,260	Dec. 18, 1917	G. Wilcox, Buena Park, Calif.
1,258,405	Mar. 5, 1918	D. A. Harrison, Los Angeles, Calif.
1,338,644*	Jan. 13, 1920	E. D. Arthur, Arcadia, Calif. and W. G. Carther, Arcadia, Calif.
1,473,018*	Nov. 6, 1923	F. E. Danner, Willows, Calif.
1,672,750	June 5, 1928	W. Christiansen, Miami, Fla.
1,837,449*	Dec. 22, 1931	C. F. Kunz, Phoenix, Ariz.
1,849,266*	Mar. 15, 1932	F. J. Bentz, Miami, Fla. (storage tank)
1,853,480*	Apr. 12, 1932	H. A. Wheeler, Miami, Fla. and F. J. Bentz, Miami, Fla.
1,888,620	Nov. 22, 1932	W. F. Clark, Philadelphia, Pa.
1,889,238	Nov. 29, 1932	Assigned to Automatic Electric Heater Co., Pollstoren, Pa.
2,065,653*	Dec. 29, 1936	H. M. Carruthers, Miami, Fla.

²Patents marked by an asterisk (*) are of the type of construction generally used in conventional solar water heaters. (Veltfort, 1942)

2,122,821°	July 5, 1938	O. H. Mohr, Oakland, Calif.
2,133,649	Oct. 18, 1938	C. G. Abbot, Washington, D. C.
2,141,330	Dec. 27, 1938	C. G. Abbot, Washington, D. C.
2,202,019	May 28, 1940	O. H. Mohr, Oakland, Calif. (cooler)
2,205,378	Jan. 25, 1940	C. G. Abbot, Washington, D. C.
2,202,756°	May 28, 1940	S. Cline, Miami, Fla.
2,208,789°	July 23, 1940	B. H. Cally, Miami, Fla.
2,213,894°	Sept. 3, 1940	E. J. Berry, Orlando Park, Fla. (45% to E. T. Buron, Winter Park, Fla.)
2,247,830	July, 1941	C. G. Abbot, Washington, D. C.
2,249,642	July 15, 1941	E. T. Turner

Patents meant little to the early builders of solar water heaters. The agrarian population living in Florida during the first quarter of the 20th century, by necessity, was skilled in building and repairing mechanical devices. Many solar water heaters were built by home owners to provide hot water on the farm or in groves where the sun provided the only readily available or affordable source of thermal energy. They most often were made up of blackened iron sheets to which the builder had clamped iron pipes arranged as in Fig. 1. Those early heat collector decks were housed in thick wooden boxes which were usually covered with glass (Veltfort, 1942). A collector area of about 12 sq ft per person was required.³ The whole south-facing system was ground mounted and connected to a large storage tank (20 gallons per person served) resting on an elevated platform. Judicious arrangement of the connecting piping allowed natural circulation of the sun heated water. Internal convection caused the stratification of the hottest water near the top of the tank, and the systems provided domestic hot water around the clock for thousands of homes in Florida by the 1920's.

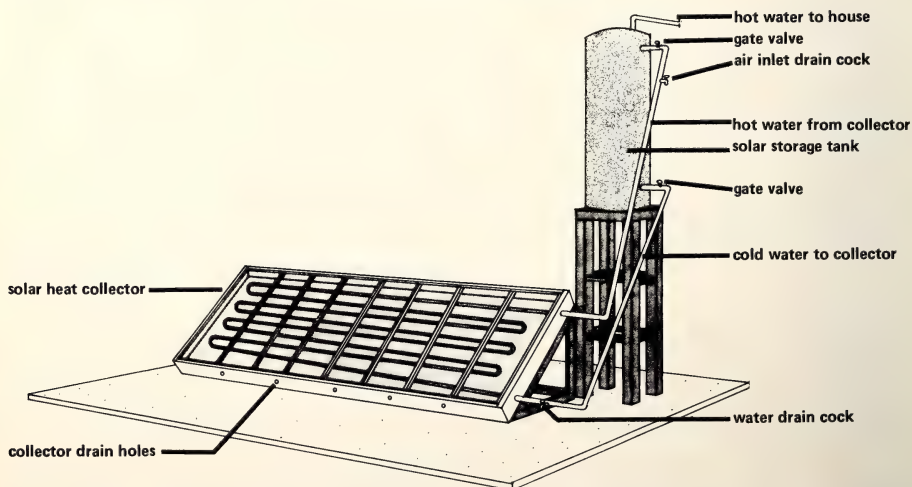


Fig. 1. Sketch of a thermosyphon solar water heater (after Partington, et al., 1975).

³As many of the events reported here occurred before the American scientific community had embraced the International System of Units and because much of the rest of it deals with such hardware as pipe and hot water tanks which are sized in inches and feet or U. S. gallons, traditional English engineering units are used except where research data cited were reported in metric units.

Early Manufacturers: Soon, roofing and plumbing contractors discovered that the making of “storeboughten” solar water heaters added a lucrative new product line to their shelf item hardware. During the 1920’s and 1930’s dozens of them began to manufacture and to refine flat plate heat collectors. A few companies were formed for the sole purpose of making and installing solar systems. By the 1940’s many heat collectors were being made with copper heat decks to which copper tubes were soldered at about 6 in intervals. They still depended upon the natural circulation caused by the density difference of the water in the hot and cold legs of their piping, but they were more efficient than their predecessors. The wooden box had given way to a more durable one made of metal which contained insulation in the form of sheeting such as “Celotex” or even mineral wool or sawdust (Hawkins, 1947). In the northern part of Florida, the units were often covered with two sheets of glass instead of one. This produced an insulating dead air space which allowed units in the colder parts of the state to operate at acceptably high temperatures even in winter. Large solar storage tanks were available from several manufacturers, solar water heaters were being incorporated into some new housing, and commercial units began appearing on hotels and apartments. Just as plumbing had been moved indoors several decades earlier, the solar heat collectors were moved from the yard to the roof where they were less subject to accidental glass breakage and where shade from growing shrubs and trees was less of a problem. The solar storage tanks were sometimes housed in an imitation chimney structure or in the attic of the building itself. Figure 2 shows such an installation which has been in use for more than



Fig. 2. A typical roof mounted thermosyphon solar water heater in Florida.

25 years. Figure 3 shows a ground mounted solar water heater which has been in use for more than 50 years. Figures 4 and 5 are from illustrations contained in the report on solar water heaters which Veltfort prepared in 1942 for the Copper and Brass Research Association.

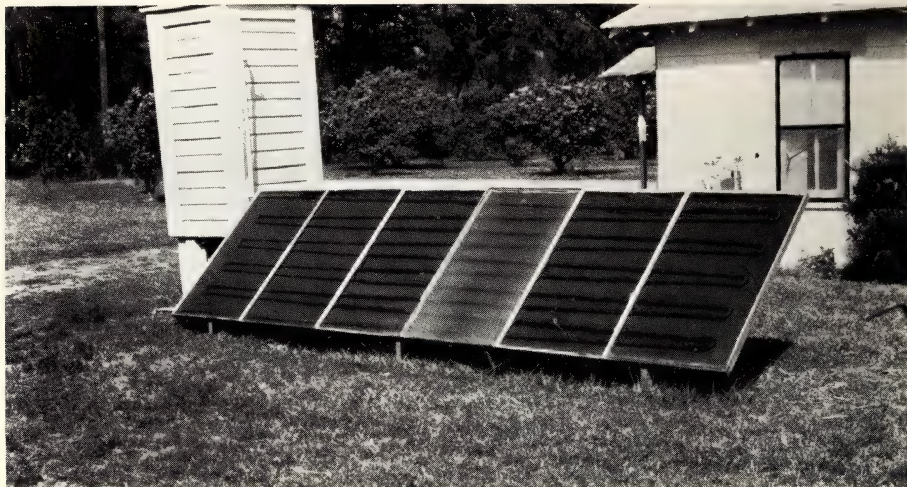


Fig. 3. A ground mounted 4×14 ft solar heat collector. The storage tank is housed in the wooden structure at the left.

Veltfort (1942) listed the following solar water heater firms and their manufacturing locations:

Bentel's Solar Heater Inc.
Miami, Florida

Bollinger Company
Lake Worth, Florida

Hot Spot Solar Heater Company
Dixie Highway
West Palm Beach, Florida

Kunz Bros. & Messenger
2 Avenue and Jackson St.
Tampa, Florida

Pan-American Solar Heater, Inc.
2730-34 Northwest 2nd Ave.
Miami, Florida (with Plant No. 2
at 212 W. Bay St., Savannah, Ga.)

Solar Water Heater Company
310 Northwest 25th St.
Miami, Florida (Branches in Nassau,
Jamaica, Bahamas, Puerto Rico, Cuba, and Manila)

Solar Water Heater Co. of Tampa
Tampa, Florida

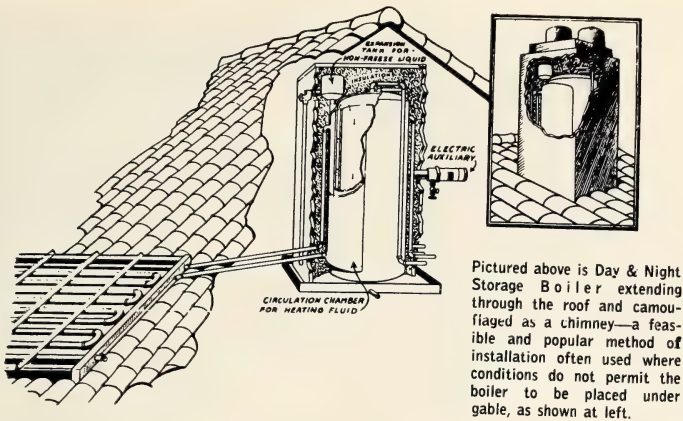
Sol-Ray Engineering Company
546 Ballough Road
Daytona Beach, Florida

Sun Heater Company
307 South Morgan Street
Tampa, Florida

Sun Ray Water Heater Co.
Sarasota, Florida

United States Foundry & Mfg. Corp.
Miami, Florida

Universal Solar Heater Company
1121 San Marco Blvd.
Jacksonville, Florida



SPECIFICATIONS

Day and Night Solar Water Heater

SUN COIL			STORAGE BOILER		
No.	Size	Approx. Weight	Capacity	Over All Dimension	Weight Installed and Filled
8	4'6"x10'0"	205 lbs.	40	5'0"x2'4"	900 lbs.
10	4'6"x12'5"	250 lbs.	60	5'0"x2'8"	1100 lbs.
12	4'6"x14'11"	335 lbs.	80	6'0"x2'8"	1450 lbs.
			120	6'0"x3'2"	2100 lbs.

The SUN COIL consists of 3/4" seamless copper tubing with return bends. The coil box is 4" thick and has 3 strips of 1/4" material on back to allow for air space between box and roof.

RECOMMENDATIONS

Type of Building	Size Sun Coil	Storage Boiler
Small bungalow	No. 8 or 10	40 gal.
Residence (1 bath and shower)	No. 10 or 12	60 gal.
2-bath residence	No. 12	80 gal.
3-bath residence	2 No. 10s	80 or 120 gals.
Extra large residence	2 No. 12s	120 gal.

Day & Night Water Heater Co., Ltd.

Fig. 4. A typical pre World War II catalog sheet of the Day & Night Solar Water Heater Co.

Early Literature: Mangon (1880) in France, Ericcson (1884), the designer of the steel ship MONITOR, and Willsie (1909) were among those who made early contributions to the solar literature. As time passed, significant contributions

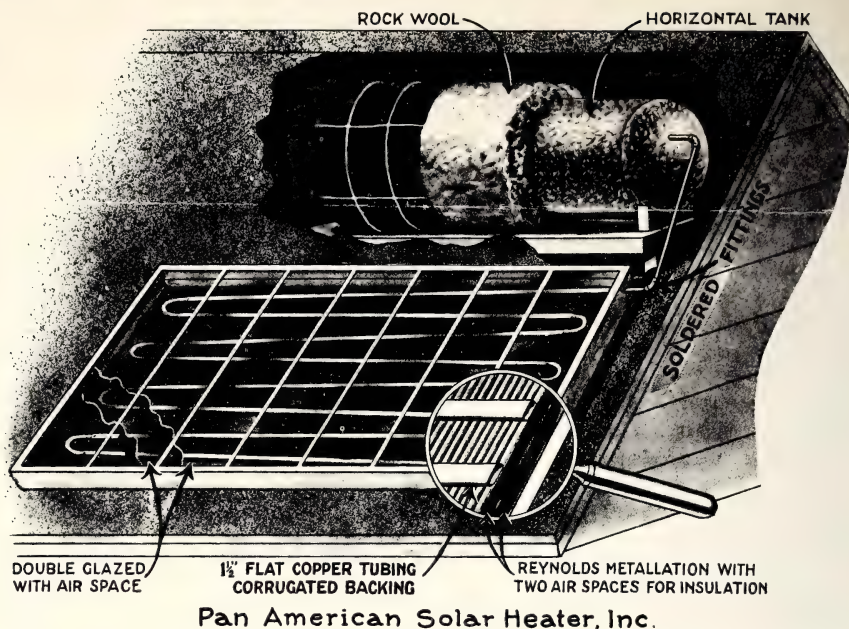


Fig. 5. The Pan American Solar Water Heater Co. sold thousands of the units shown here during the 1930's, 1940's and 1950's. Many of them were installed in government housing projects established for low income groups.

were made by Farrall (1929), Carnes (1932), Alt (1935), Brooks (1936), Abbot (1934, 1939), Merle (1940), Moon (1940), Cottony (1941), and Hottel and Woertz (1942).

University Participation: Solar research work at Harvard and Massachusetts Institute of Technology received the financial support of the Godfrey Cabot Foundation during the mid-1930's, at which time there were only two other such programs. One was conducted in Algeria, the other at Tashkent in Russia (Hottel and Howard, 1971). The University of Florida and the University of Wisconsin initiated research programs within the next few years and it looked as if the practical application of solar energy was off and running. By 1951, there were more than 50,000 solar water heaters in use in the Miami area alone (Hottel, 1955).

BUT, something went awry—

By the mid-sixties public interest in purchase of solar water heaters had all but disappeared throughout the *entire* United States and the marketplace no longer supported the industry. Accordingly, innovation for product improvement ceased as companies failed or reverted to previous product lines such as plumbing and roofing. Interest in solar energy continued among a few scientists such as Farrington Daniels who was directing much of his attention to solar stills to create fresh water—something which holds future promise in Florida as demands on our fragile and limited aquifers intensify with exploding population. Daniels (1956) had an extraordinary perception of energy problems clearly

stated in his keynote address at the First World Symposium on Applied Solar Energy held in Phoenix, Arizona, in November, 1955. In any event, as popular interest in applied solar energy declined in the U. S., scientific and popular interest developed abroad, especially in Australia, Israel, France and Japan.

Several causes have been suggested for the decline in American interest. Scott et al. (1974) summarized their south Florida survey findings as shown in Table 1.

TABLE 1. Reasons for discontinuing the use of solar hot water heaters.

Condition	Absolute Frequency	Percent Frequency
Damage caused by tank leaks	16	24.0
Insufficient hot water	15	23.0
Too expensive to repair tanks	10	15.0
Replaced before failure, unit considered too old	6	9.1
Poor position, shading	4	6.1
Not safe, worrisome	3	4.5
Booster problems	3	4.5
Too much rust or sediment	2	3.0
Needed maintenance, bother	2	3.0
Damaged by storms	1	1.5
Already had conventional unit	1	1.5
Other	3	4.5

Tanks mounted above ceilings were generally set in drip pans to which drain lines were connected. However, the drain lines often became clogged with trash during their 10-20 yr of dormancy prior to tank failure. This meant wet and often falling plaster was the first warning many home owners had that their attic mounted solar tank had sprung a leak. As Scott's survey reports, this turned many solar water heater owners toward electric or gas units. Eric Farber, long time director of the Solar Energy Laboratory at the University of Florida, noted additionally that the mass purchase of fully automatic washing machines and dishwashers during the late 1950's and into 1960's put too much demand on many solar hot water systems (Farber, personal communication, 1974).

High initial cost had always been a deterrent to the sale of solar water heaters. They remained batch produced by relatively small manufacturers, but electric and gas water heaters, as demand grew, became mass produced by major firms. The solar systems stayed expensive while the electric and gas units became very inexpensive during the 1960's.

The power of advertising may have been a contributor to declining public interest, too. During the sixties, electrical energy became so abundant that power companies spent millions urging the public to buy "gold medallion all electric homes" or to "live better electrically." The power companies offered cash rebates to those who installed electric hot water heaters. During that period the Florida homeowners averaged paying about \$0.017 per KWH for electric power (the 1976 average is ca. \$0.04).

Probably because of the combined negative effects of the problems caused by tank leaks and others cited by Scott and Farber, and positive pressures for change exerted by the utility companies and conventional water heater manufacturers, few solar water heaters were sold in Florida from 1960 until about 1975 and most of the manufacturing capability was lost.

On a national level, scientific interest dwindled. Researchers had found what appeared at the time to be a safe and nearly inexhaustible source of power—light water nuclear reactors. By 1965, only a handful of university level research scientists continued their interest in the solar field. Farber at the University of Florida, Daniels and Duffie at the University of Wisconsin, Löff in Colorado, Bliss and Yellott in Arizona, Hottel at M. I. T., Jordan at the University of Minnesota, and Telkes in New York (later Delaware) were notable among these.

Fortunately, as noted previously, growing interest outside the United States on the part of numerous scientists in Australia, Israel, South Africa, Japan and France helped keep scientific investigation alive. The activity in Australia was great enough to provoke the moving of the headquarters of the International Solar Energy Society to Melbourne in 1970. (The Society had been formed in the mid-1950's in Phoenix, Arizona, as the Association for Applied Solar Energy and it had sponsored the First World Symposium on Applied Solar Energy in that city November 1-4, 1955.)

As the 1960's passed, solar water heaters disappeared from the roofs in Florida—and in Arizona, New Mexico and southern California, too, for that matter. Solar manufacturing companies dwindled to a very few, and solar scientists in general devoted their efforts to other fields of research. The interest level in the practical utilization of solar energy can be traced as an ever descending curve across the last 5 yr of the sixties and by 1970 interest was almost gone.

Something else was almost gone by 1970, too, but few recognized the danger signals.

Cheap energy was almost gone—

That fact is well understood now. In a speech delivered in Washington, D. C., January 30, 1976, to the American Institute of Aeronautics and Astronautics, Robert Fri, Deputy Administrator for ERDA, stated that proven petroleum reserves will last about another 35 yr, but that uneven geographical distribution will cause shortages in Western bloc nations to occur far short of that time. That's a sobering statement, since Mr. Fri has access to the most accurate information available on that subject. It is not likely that petroleum can ever again be looked to as a source of cheap energy.

Near cessation of construction of new nuclear power plants is documented in an article on atomic power which appears in the February 16, 1976, issue of *U. S. News and World Report*. Supplemental electrical energy from that source is going to amount to considerably less than had been expected.

ERDA's National Energy Research and Development Plan is excerpted and highlighted in a special issue of *Information from ERDA* dated November 21,

1975. It is apparent from this publication that the homeowner can expect little relief from constantly increasing power costs before at least 1985. That is to say, little relief in terms of the new technology which ERDA expects to develop and market. Hottel and Howard (1971) have analyzed, in depth, most suggested long range solutions to the growing world energy demand.

A NEAR TERM PROSPECT FOR RELIEF—What about an old technology? What about the solar water heater? What about solar building heating? What about solar operated air conditioning? In Florida homes 85% of the energy consumed is for these three items (Farber, 1975).

By way of answering those questions, let us review the Solar Conference of February 13-14, 1976, sponsored by the Associated Plumbing and Mechanical Contractors of Florida in Orlando. That it was attended by people from 22 states, including Alaska and several Caribbean countries is interesting, though not surprising. There *was* something surprising about that conference, however. Some 42 manufacturers displayed solar devices ranging from differential thermostats to complete solar heating systems for buildings. The three largest manufacturers of conventional water heaters in the world displayed solar storage tanks. Two of the three displayed several different types of complete solar systems. Two large and respected aerospace firms displayed flat plate collectors and systems for water heating and hydronic building heating.

The largest plumbing supply house in Florida displayed solar heat collectors and complete solar water heating systems which it manufactures. One of the nation's largest aluminum and copper fabricators displayed both copper and aluminum panels with integral tubing systems made exclusively for use in solar heat collectors. One of the largest glass manufacturers in the world displayed flat plate solar heat collectors. A Texas manufacturer of air conditioning components displayed a tracking solar collector which utilizes a rectangular Fresnel lens and is said to produce water or steam at temperatures suitable for powering absorption air conditioners.

These were not handmade prototypes on display. These were production models ready for delivery now.

Considered collectively, these displays indicate that those planning the economic future of some very large companies, with widely divergent interests, have reached a similar conclusion. Their conclusion would seem to be that the practical application of solar energy is going to make a comeback in the U. S.

AVAILABILITY OF SOLAR ENERGY—Even superficial study of insolation data (Fig. 6, 7 and Table 2) establishes that sufficient solar energy is available, in most of the United States, to heat a house and its hot water or to power its air conditioner without using more than half the surface of the roof for solar heat collection. Insolation data measured on a horizontal surface tends to give the southwest, and to a lesser extent, the entire south a distinct advantage in terms of the quantity of solar energy impinging on the surface. However, if the insolation figures are corrected to reflect the quantity of energy which impinges on a properly sloped surface, the apparent locational differences are smaller. Figures 6 and 7 illustrate this.

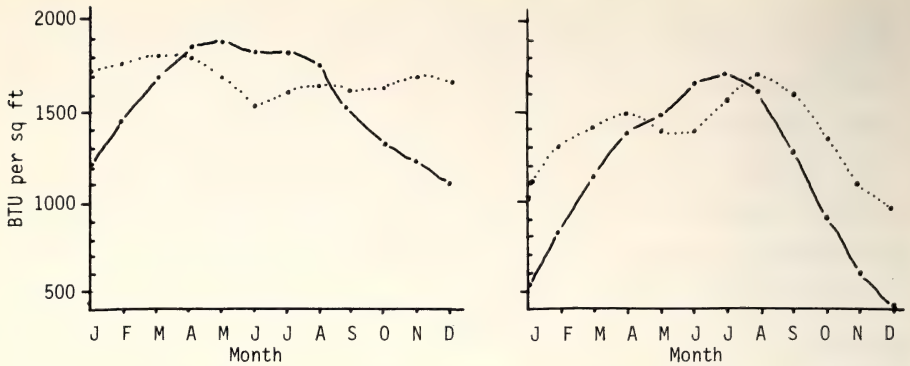


Fig. 6 (left). Monthly distribution of mean daily insolation in BTUs per sq ft in Miami, Florida. The solid line indicates levels for a horizontal surface based upon mean daily solar radiation for 1964. The dotted line indicates levels for a south facing surface elevated from horizontal to an angle equal to the latitude plus 10° .⁴

Fig. 7 (right). Monthly distribution of mean daily insolation in BTUs per sq ft in Cambridge, Massachusetts, based on data parallel to that in Fig. 6.

The solar climate has not changed since the “old” solar industry died in the 1960’s. What is to prevent the renewed interest in the sun’s energy from dying out again? While the solar climate hasn’t changed, the energy climate has changed—markedly.

Energy in the 1950’s and 1960’s was so cheap it was basically free. Energy consumption was not even considered in most manufacturing operations. Gasoline price wars were the rule rather than the exception for the last half of the sixties. Utility companies used every technique known to merchandisers to sell more electricity and natural gas at giveaway prices. That was the energy climate surrounding the waning Florida solar water heater industry of yesteryear.

There is simply no hope that such a situation will occur again. Oil rich nations have realized they are custodians of an exhaustible asset which requires millions of years to replenish. Some responsible scientists hold that nuclear power plants have turned up about as many problems as they have solutions. Fluidized bed coal generating plants will help, but their construction will take time and the cost of operation is expected to be higher than the currently operable oil and gas fired generating plants. Environmentalists are less than overjoyed at the prospect of renewed strip mining of coal to fuel them. Wind power, ocean thermal gradients, bioconversion and direct production of electricity from sunlight—all of these things offer promise in the future, but the hardware is neither available for mass purchase nor economically competitive *yet* (Harrenstien, 1976).

⁴The values given represent a first approximation approach to the actual amount of insolation received. Geometrical considerations dictate that a sloping surface intercepts more direct or beam radiation than a horizontal one during the winter season. During the winter, overcast days are few and probably more than 80% of the total insolation is direct. Because of rain showers, however, much of the summer insolation any surface receives is diffuse. Tilting the surface may increase or decrease its ability to receive diffuse radiation on overcast days, cloud reflected radiation when cumulus clouds abound and ground reflected radiation from lakes and fields. Many investigators have suggested methods for evaluating both the beam and diffuse radiation received by variously oriented surfaces. Among them are: Moon (1940), Hottel & Woertz (1942), Brooks (1952), Becker and Boyd (1957), Bliss (1961), Liu and Jordan (1967), Duffie and Beckman (1974), and Hottel (1976).

TABLE 2.
MEAN DAILY SOLAR RADIATION (Langleys) AND YEARS OF RECORD USED

STATES AND STATIONS		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
		VRS	VRS	VRS	VRS	VRS	VRS	VRS	VRS	VRS	VRS	VRS	VRS	VRS
ALASKA, Annette Barrow	#	6	115	6	7	364	8	438	6	341	6	258	7	122
	#	63	8	180	8	513	8	528	8	255	9	255	10	115
		38	9	108	10	282	9	444	10	376	10	252	10	202
		16	25	71	27	213	25	376	28	461	28	504	29	180
Fairbanks		32	6	92	6	242	4	356	7	462	6	314	6	198
		300	2	382	3	526	3	618	2	707	2	680	3	596
		301	11	409	11	526	11	638	11	739	11	739	11	613
		315	5	391	5	540	4	655	5	699	5	626	6	588
ARK., Little Rock		188	9	260	9	353	10	446	9	523	9	559	9	556
		174	18	257	17	390	18	528	18	694	18	682	18	612
		184	31	289	31	427	31	552	31	702	32	682	32	621
		306	11	412	11	562	11	683	11	819	11	772	11	729
CALIFORNIA, Davis		244	19	302	18	397	19	457	20	506	19	487	21	497
		248	10	321	10	470	10	515	9	596	9	641	9	581
		243	9	327	9	436	9	483	9	555	9	651	9	581
		273	8	367	8	478	9	541	9	680	9	673	9	618
Inyofern (China Lake)		263	11	346	11	462	11	552	10	635	11	613	11	524
		223	4	316	3	374	4	551	4	691	4	760	3	681
		201	5	268	4	401	4	460	4	525	5	520	5	439
		227	9	324	8	435	8	546	8	695	8	708	8	595
D. C., Washington (C.O.)		212	6	313	7	423	7	512	8	632	8	600	8	505
		174	3	266	3	344	2	381	2	494	2	536	2	446
		158	39	531	39	322	39	398	39	467	39	476	39	440
		177	7	247	6	342	7	538	7	613	7	529	9	531
American University		296	10	367	10	441	10	533	10	578	9	461	10	400
		297	11	330	10	411	10	463	10	549	10	488	10	483
		279	11	343	10	427	12	579	12	521	10	488	10	483
		274	12	341	12	541	12	571	10	532	10	505	10	505
FLA., Apalachicola		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
Belle Isle		296	10	367	10	441	10	533	10	578	9	461	10	400
		297	11	330	10	411	10	463	10	549	10	488	10	483
		279	11	343	10	427	12	579	12	521	10	488	10	483
		274	12	341	12	541	12	571	10	532	10	505	10	505
Gainesville		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
Miami Airport		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
Malinassee		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
Tampa		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
Griffin		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
HAWAII, Honolulu		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
Maunaloa		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
Pearl Harbor		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505
		279	12	341	12	541	12	571	10	532	10	505	10	505
		274	12	341	12	541	12	571	10	532	10	505	10	505

TABLE 2 (cont.)

IDAHO, Boise	138	10	236	9	342	9	485	9	585	10	636	9	670	10	576	10	460	10	301	11	182	11	124	11	395
Twin Falls	163	20	240	20	355	20	462	21	532	20	592	18	602	20	540	20	432	19	286	20	176	20	131	19	278
ILL., Chicago	96	19	147	19	227	19	331	19	424	19	456	18	473	19	403	18	313	19	207	20	120	20	76	20	373
Lemont	170	6	242	6	340	6	402	6	506	6	553	6	583	6	498	6	398	5	275	5	165	5	138	5	345
IND., Indianapolis	144	10	213	10	316	10	396	10	488	9	543	11	541	10	490	11	405	11	293	11	177	11	132	11	345
IOWA, Ames	174	5	253	5	326	5	403	5	480	5	541	5	546	5	460	6	367	6	274	7	187	7	143	7	345
KANS., Dodge City	255	7	316	7	418	7	528	7	568	7	630	7	642	7	592	7	493	9	380	9	285	10	234	10	447
Manhattan	192	3	264	3	345	3	433	3	527	4	531	4	526	4	426	4	410	4	292	4	247	4	156	4	371
KY., Lexington	172	9	263	9	357	10	480	10	581	10	628	9	617	10	563	10	494	10	357	9	245	9	174	11	411
LA., Lake Charles	245	11	306	11	397	11	481	11	555	11	591	11	596	11	511	11	443	11	402	11	300	10	250	10	418
New Orleans	214	14	259	14	335	15	412	16	449	14	443	13	417	15	416	15	383	15	357	13	278	13	198	14	347
Shreveport	232	3	292	3	384	3	446	4	558	4	557	4	578	4	528	4	414	4	354	4	254	4	205	4	400
MAINE, Caribou	133	8	231	9	364	8	409	10	476	10	508	11	508	11	448	11	336	11	212	11	111	11	137	9	316
Portland	152	7	235	8	352	7	409	9	514	9	539	9	561	9	488	8	383	7	278	9	157	8	117	9	350
MASS., Amherst	116	2	*	300	2	*	431	2	514	2	514	2	514	2	449	2	354	2	266	2	182	2	124	2	328
Blue Hill	153	27	228	27	319	26	389	26	469	27	510	27	502	26	449	27	354	28	266	28	162	28	135	28	328
Boston	129	16	194	17	290	17	350	17	445	16	483	16	486	16	411	16	334	17	235	16	136	16	115	15	301
Cambridge	153	4	235	3	323	3	400	3	420	3	476	3	482	4	464	4	367	4	253	4	164	4	124	4	322
East Wareham	140	13	218	13	305	12	385	14	452	14	508	14	495	14	436	14	365	13	238	14	163	14	140	13	322
Lynn	118	2	209	2	300	2	394	2	454	2	549	4	528	4	432	3	341	2	241	3	153	3	107	3	317
MICH., East Lansing	121	10	210	11	309	11	359	11	483	10	547	11	540	11	466	11	323	11	235	11	136	11	108	11	311
Sault Ste. Marie	130	10	225	9	356	10	416	10	523	10	557	11	573	11	472	10	322	10	216	9	105	9	96	9	333
MINN., St. Cloud	168	8	260	8	368	8	426	8	496	8	535	8	537	9	486	8	366	8	237	7	146	8	124	8	348
MO., Columbia (C. O.)	173	10	251	10	340	11	434	11	530	11	574	11	574	10	522	10	453	10	322	10	225	10	158	9	380
University of Missouri	166	5	248	6	324	6	429	6	501	6	560	6	563	6	509	6	417	6	264	5	177	5	146	5	365
MONT., Glasgow	154	6	258	8	385	7	466	8	568	8	605	8	643	8	531	8	407	10	267	8	154	8	116	7	388
Great Falls	140	8	232	9	366	9	434	8	528	8	583	8	639	9	532	9	407	10	264	10	154	10	112	10	366
Summit	122	3	162	2	268	3	414	3	462	3	493	3	560	2	510	2	354	2	216	2	102	2	76	2	312
NEBR., Lincoln	188	39	259	39	350	39	416	39	494	40	544	38	568	38	484	38	396	38	296	36	199	40	159	39	363
North Omaha	193	3	299	3	365	3	463	3	516	3	546	4	568	4	519	4	410	4	298	4	204	4	170	4	379
NEV., Ely	236	7	339	7	468	7	563	7	625	10	712	10	647	11	618	11	518	11	394	10	289	10	218	10	469
Las Vegas	217	11	324	11	418	11	501	11	702	11	748	10	675	11	627	11	551	11	429	11	318	11	258	11	509
N. J., Seabrook	157	8	278	8	378	8	463	8	548	8	605	8	643	8	531	8	407	10	264	10	154	10	112	10	366
N. H., Mt. Washington	157	8	278	8	378	8	463	8	548	8	605	8	643	8	531	8	407	10	264	10	154	10	112	10	366
N. Mex., Albuquerque	303	12	386	13	511	13	618	13	686	13	726	13	683	12	626	13	554	14	438	15	334	15	276	14	512
N. Y., Ithaca	116	22	194	21	272	23	334	23	440	24	501	23	459	23	453	23	346	21	231	22	120	23	96	23	302
N. Y., Central Park	130	34	199	34	290	33	369	33	432	35	470	34	459	35	389	35	331	36	242	36	147	36	115	35	298
Saville	160	11	249	11	325	10	415	10	494	10	565	10	545	10	462	10	385	10	289	10	186	10	142	11	352
Schenectady	130	8	200	9	273	9	338	9	413	9	448	8	441	8	397	8	299	8	218	8	128	8	104	8	282
Upton	155	8	232	8	339	8	428	8	502	8	573	8	544	7	475	7	391	7	293	6	182	7	146	7	355
N. C., Greensboro	200	7	276	9	354	9	469	9	531	10	564	10	544	10	485	10	406	10	322	10	243	10	197	8	383
Hatteras	238	10	317	9	426	8	569	9	635	10	652	10	625	10	562	11	471	11	358	11	282	11	214	11	443
Raleigh	235	3	302	2	*	466	3	494	2	564	2	535	3	476	3	379	3	307	3	235	3	199	3	---	3
N. D., Bismarck	157	7	250	8	356	6	467	8	550	8	590	9	617	10	516	11	390	11	272	11	161	10	124	10	369
OHIO., Cleveland	125	6	183	6	263	7	346	6	429	6	502	8	562	8	494	8	278	8	289	9	141	9	115	7	335
Columbus	128	7	200	7	297	7	381	7	471	7	562	7	562	7	477	4	423	4	286	4	176	4	129	5	340
Put-in-Bay	126	10	204	9	302	10	386	11	468	11	544	11	561	10	487	10	382	11	275	11	144	11	109	11	332

TABLE 2 (cont.)

OKLA., Oklahoma City	251	10	319	10	409	9	494	10	536	10	615	7	610	8	593	8	487	9	377	10	291	9	240	9	436
Stillwater	205	8	289	8	390	9	454	9	504	9	600	10	596	10	545	10	455	11	354	10	269	9	209	8	405
OREG., Astoria	90	7	162	8	270	8	375	8	469	8	542	8	539	8	461	7	354	7	209	8	111	8	79	8	301
Corvallis	89	2	215	11	287	3	406	3	517	3	570	3	676	4	558	4	397	4	235	4	144	4	80	4	---
Medford	116	11	336	11	482	11	486	11	592	11	652	11	698	10	605	11	447	11	279	11	149	11	93	11	389
PA.,Pittsburgh	94	6	169	5	216	6	317	6	429	6	491	6	497	7	409	6	339	6	207	5	118	6	77	5	280
State College	133	19	201	19	295	20	380	20	456	20	518	20	511	20	444	20	358	20	256	20	149	20	118	20	318
R. I., Newport	135	23	232	22	334	23	405	23	477	23	527	24	513	24	455	24	377	24	271	24	176	24	139	24	338
S. C., Charleston	252	11	314	11	388	11	512	11	551	11	564	11	520	11	501	11	404	11	338	11	286	11	225	11	404
S. D., Rapid City	183	11	277	11	400	11	482	11	532	11	585	11	590	11	541	11	435	11	315	10	204	10	158	10	392
TENN., Nashville	149	18	228	19	322	19	432	19	503	18	551	18	530	17	473	17	403	17	308	19	208	18	150	19	355
Oak Ridge	161	11	239	11	331	11	450	11	518	11	551	11	526	11	478	11	416	11	318	11	213	10	163	11	364
TEXAS, Brownsville	297	10	341	10	402	10	456	10	564	10	610	9	627	8	568	11	475	11	411	11	296	11	263	10	442
El Paso	333	11	430	11	547	10	654	11	714	11	729	11	656	11	640	10	576	11	460	11	372	11	313	11	536
Ft. Worth	250	11	320	11	427	11	488	11	562	11	651	11	613	11	593	11	503	11	403	11	306	11	245	9	445
Midland	283	7	358	8	476	9	550	8	611	8	617	8	608	7	574	8	522	9	396	9	325	8	275	8	466
San Antonio	279	9	347	9	417	9	445	9	541	9	612	9	639	9	585	9	493	10	398	10	295	10	256	8	442
UTAH, Flaming Gorge	238	2	298	2	443	2	522	2	565	2	650	2	599	3	538	3	425	3	352	3	262	3	215	3	426
Salt Lake City	163	8	256	8	354	8	479	8	570	7	621	7	620	6	551	7	446	8	316	8	204	8	146	9	394
VA., Mt. Weather	172	2	274	2	338	2	414	2	508	2	525	3	510	3	430	3	375	3	281	2	202	2	168	2	350
WASH., North Head	*	167	2	257	3	432	2	509	3	487	3	486	3	436	3	321	3	205	3	122	3	77	3	---	
Friday Harbor	87	8	157	7	274	8	418	8	514	9	578	10	586	10	507	11	351	8	194	10	102	10	75	8	320
Prosser	117	4	222	4	351	4	521	5	616	4	680	4	707	4	604	4	458	4	274	4	136	4	100	4	399
Pullman	121	4	205	2	304	2	462	2	558	4	653	5	699	5	562	4	410	4	245	5	146	5	96	5	372
University of Washington	67	9	126	9	245	10	364	9	445	10	461	10	496	11	435	10	299	8	170	9	93	9	59	9	272
Seattle-Tacoma	75	9	139	9	265	9	403	9	503	9	511	9	566	9	452	10	324	10	188	10	104	9	64	10	300
Spokane	119	8	204	8	321	8	474	9	563	9	596	9	665	9	556	9	404	10	225	9	131	9	75	7	361
WIS., Madison	148	46	220	46	313	45	394	47	466	47	514	47	531	47	452	47	348	47	241	47	145	44	115	46	324
WYO., Lander	226	8	324	9	452	9	548	11	587	11	678	11	651	11	586	10	472	8	354	9	239	9	196	9	443
Laramie	216	3	295	3	424	3	508	3	554	3	643	3	606	3	536	3	438	3	324	3	229	3	186	4	408
ISLAND STATIONS																									
Canton Island	588	9	626	7	634	7	604	9	561	9	549	8	550	9	597	9	640	9	651	9	600	8	572	8	597
San Juan, P. R.	404	5	481	4	580	4	622	4	519	5	536	6	639	5	549	6	531	6	460	6	411	6	411	6	512
Swan Island	442	6	496	7	615	6	646	6	625	6	544	8	588	8	591	7	535	8	457	7	394	8	382	8	526
Wake Island	438	7	518	7	577	7	627	7	642	8	656	6	629	7	623	7	587	6	525	7	482	7	421	7	560

NOTES:

- * Denotes only one year of data for the month -- no means computed.
 --- No data for the month (or incomplete data for the year).
 # Barrow is in darkness during the winter months.
 + Madison data after 1957 not used due to exposure influences.
 ‡ Riverside data prior to March 1952 not used--instrumental discrepancies.
 Langley is the unit used to denote one gram calorie per square centimeter.

Economic Parameters: The displays in Orlando establish that solar heat collectors and complete solar water heating systems are *available*, but are they *economically competitive*? Opinions vary. Florida Power's manager of energy conservation doubts that many people will think that they are (Weatherington, 1975). On the other hand, some consumers may subscribe to the economic viewpoint presented in Table 3 (Root, 1976).

While solar building heating would hardly be considered sensible in most of Florida (heating is required too few hr per yr), it is stated by responsible researchers to be competitive with electric heat in many parts of the United States (Faltermayer, 1976; Hottel and Howard, 1971).

Solar air conditioning offers great challenge in climates such as Florida enjoys since it is most needed when solar intensity is at its peak. At least some recognized researchers in the solar field see no reason why hardware cannot be produced now which will satisfy the physical and economic requirements for solar powered air conditioning systems (Farber, et al., 1966).

Current Production: In 1974 only 136,540 sq ft of medium temperature heat collectors are thought to have been produced in the United States. The first half of 1975 brought increased production to 276,466 sq ft (F. E. A., 1975). The annual figure for 1975 is given as 675,000 sq ft by Neil Barker, Manager for Solar System Sales, Glass Division, PPG Industries.

Solar heating of swimming pools consumed 2,072,556 sq ft of low temperature heat collectors from January through June, 1975—up from 1,137,196 sq ft for the entire yr of 1974 (F. E. A., 1975).

ERDA's catalog of solar energy heating and cooling products (ERDA, 1975) lists over 460 manufactured components currently being offered. Their list, by their own statement, is very incomplete.

So—even though the solar climate has not changed since the 1960's, the economic climate is more favorable for the development of solar devices. Major firms with a history of backing up their products are offering wares in the solar marketplace. After spending less than \$100,000 per yr on solar research and development from 1950-1970 (Hughes, 1974), the federal government spent \$86 million last year and will spend over \$250 million this coming year for solar research and demonstration projects. Solar workshops throughout the country have been over-subscribed for more than a year. Walter Morrow, Associate Director of M. I. T.'s Lincoln Laboratories, reflected this reemerging interest by titling his December, 1973, article in *Technology Review* "Solar Energy: Its Time is Near."

Available Hardware—With such a profusion of products being offered for sale, it may be well to examine some construction methods and materials which are being used in solar components, especially water heaters.

Since the sun is an intermittent source of energy, most solar systems use a storage bank of some kind to store heat for use when the sun isn't shining. It should be noted that very long term storage is not easy to justify in terms of economic feasibility—nor is it often required. Erich Farber reported to the AP&MC of Florida Solar Conference in February of 1976 that his staff had scrutinized

TABLE 3. Solar Economic Analysis.¹ Rule of thumb economics for a family of four, paying \$0.04 per KWH for electricity used to heat domestic hot water, in a city with a temperate climate (for instance, Atlanta, Georgia). (after Root, 1976)

Earnings	Investment	Total Taxable Income	Tax (20%)	Expenses	Annual Increase in Net Income
\$10,000	none	\$10,000	\$2,000	\$8,000	none
\$10,000	\$1,000 in bank @ 6%	\$10,060	\$2,012	\$8,000	\$48.00
\$10,000	\$1,000 in solar water heater (paid in cash from savings)	\$10,000	\$2,000	\$7,820 (\$180 saved on utility bill)	\$180.00
\$10,000	\$1,000 in solar water heater (all borrowed @ 10%)	\$9,900 (\$100 interest deduction)	\$1,980	\$7,920 (\$180 saved on utilities; \$100 paid in interest)	\$100.00
\$10,000	\$1,500 in bank @ 6%	\$10,090	\$2,018	\$8,000	\$72.00
\$10,000	\$1,500 in solar water heater (paid in cash from savings)	\$10,000	\$2,000	\$7,820	\$180.00
\$10,000	\$1,500 in solar water heater (all borrowed @ 10%)	\$9,850	\$1,970	\$7,970	\$60.00

¹In this analysis, the quality of the solar heating system is assumed to be such that it will: 1) heat 90% of the hot water required; 2) not require maintenance which the home owner cannot perform himself (for example, oiling motor bearings); and 3) add \$1,000 (\$1,500) to the value of the home should the owner decide to sell and move elsewhere.

weather data covering many years and concluded that very rarely are there three consecutive days with less than 1/3 of the maximum insolation available anywhere in the 48 contiguous United States. At most, two or three days supply of energy may reasonably be used as the sizing criterion. Economic considerations dictate that solar systems be backed by standby fossil fueled or electric heaters. In the case of solar water heaters, only a single day's supply is usually stored.

Solar energy is often stored as low temperature (ca. 180°F) heat if it is collected with a flat plate heat collector. Because water is inexpensive, relatively easy to handle and contain and capable of storing acceptable quantities of energy in a small volume, it is used as a heat storage medium more often than any other material. However, extensive work has been carried out on change of state materials which have relatively short cyclic lives but do store up to an order of magnitude more energy per unit volume than does water (Telkes, 1956, 1973). At

present, many investigators think that the problems presented outweigh the advantages offered by such a heat storage system for the practical heating and cooling of buildings.

When air is used as a heat collection fluid, a bin of golf-ball-sized rocks is often used as a heat storage bank (Bliss, 1955; Löff, 1955, 1974). A rock bin should have approximately twice the volume of a water tank for equal storage capacity (ΔT being equal in both cases). As water is the most widely used storage medium, let us examine its use more closely.

Comparatively few thermosyphon solar systems are being installed at the present time. That system included no moving parts, was self-regulating in terms of flow rate and required little attention except for freeze protection, but the elevated position of the storage tank was a problem from all standpoints.

Most modern solar water heating installations include a small circulating pump and a differential sensor system to control the on-off mode of that pump (Fig. 8.) If water is circulated through a heat collector in locations where freezing temperatures are encountered, provisions must be made to protect the pipes from freezing. Some manufacturers recommend using valves to isolate the collector and exposed piping, and draining the endangered sections. It must be remembered that some tubing systems are not designed to drain completely and they must be protected by other means (Fig. 9). In areas where freezing temperatures are only occasionally encountered, some circulating pump controls are equipped with "freeze-sensors" which turn them on intermittently during near-freezing conditions. This intermittent circulation of hot water from the storage tank prevents freezing automatically (as long as no power failures are experienced), but uses up some stored energy to accomplish the goal.

In areas where freezing temperatures often accompany the winter months, a non-freezing liquid may be used to transport energy from the heat collector to a

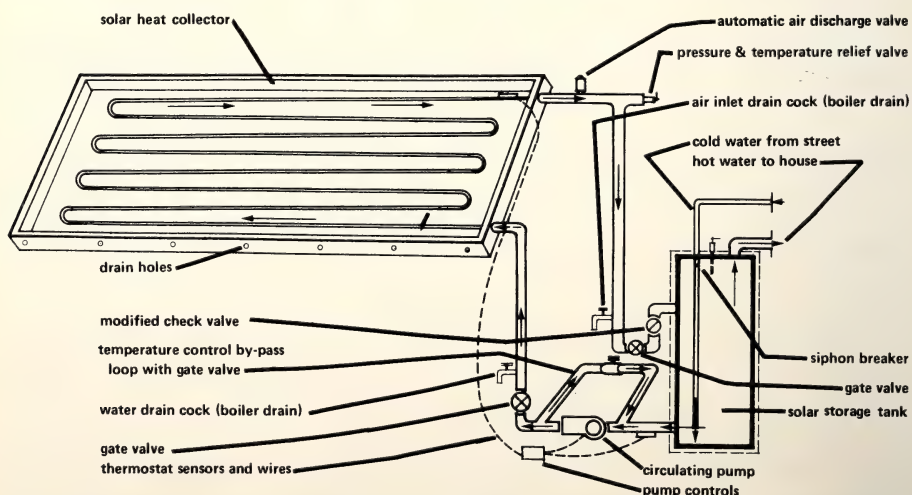


Fig. 8. Conceptual drawing of a forced circulation solar water heater (after Partington, et al., 1976).

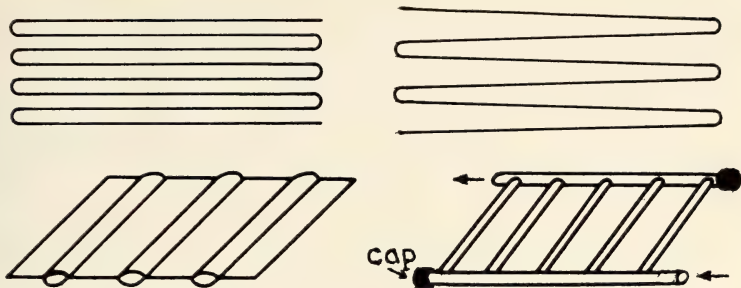


Fig. 9. Various configurations of pipe grids in solar collectors: upper left, parallel horizontal; upper right, sloped horizontal; lower left, tube-in-sheet; and lower right, vertical tubes with headers.

heat exchanger which, in turn, transfers it to the storage tank. Because many antifreeze solutions and corrosion inhibitors are toxic, external “wrap around” heat exchangers are used to guarantee double walled separations from what is usually potable water in the storage tank (Fig. 10). Though most heat collectors being sold in Florida at this time are offered with one of these three types of freeze protection, sump tanks are sometimes used with large collector systems to allow untreated water to gravity drain when the pump is turned off.

Concentrating vs. Flat Plate Collectors: Concentrating parabolic troughs and long rectangular Fresnel lenses are sometimes used in conjunction with darkened absorbing surfaces to produce higher temperatures than can be obtained with flat plate heat collectors (Fig. 11). Flat plate collectors are usually mounted fac-

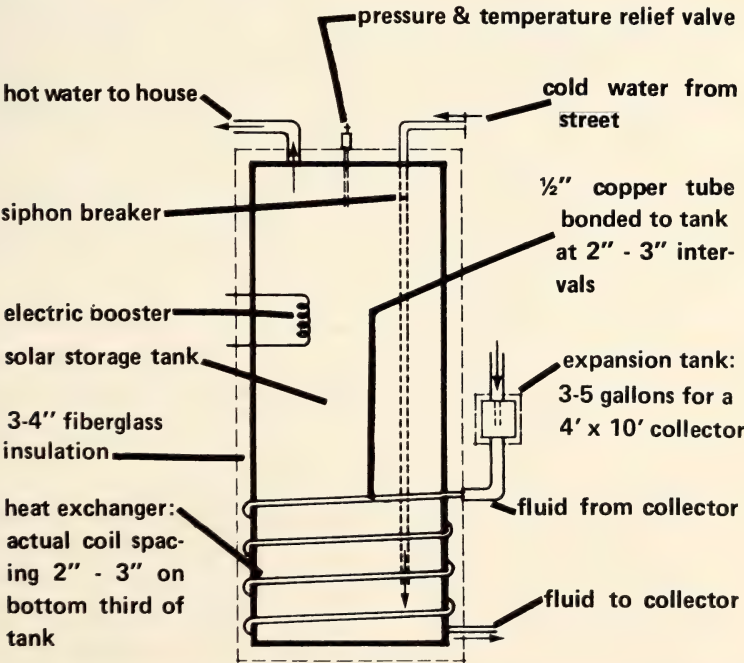


Fig. 10. Conceptual drawing of an external heat exchanger on a solar storage tank (after Partington, et al., 1976).

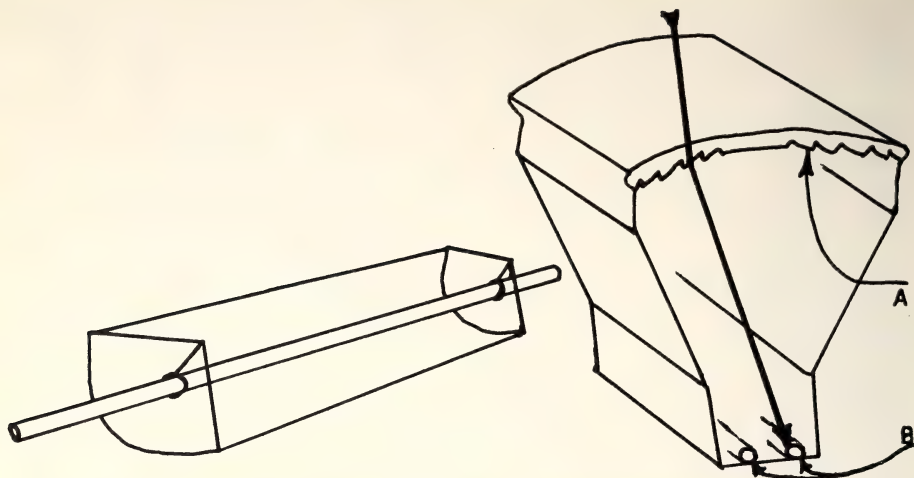


Fig. 11. Concentrating solar collectors: left, reflecting trough; and right, section of Fresnel lens collector (A indicates the lens and B the collecting tubes).

ing south in a fixed position at angles of elevation shown in Fig. 12. Concentrating collectors, on the other hand, more often track the sun from morning to night and are periodically or continuously adjusted to compensate for seasonal variations in solar altitude.

Both focusing and flat plate collectors have their virtues and their shortcomings. Flat plate collectors are capable of converting diffuse solar energy into heat and thus work about 20% as well on a cloudy day as a sunny one. Unfortunately, concentrating collectors do not have this capability, so even though they collect energy at a higher temperature (200° - 1200° F) and often absorb more energy per min of sunlight exposure, they seldom collect much more energy per unit area of aperture than does the flat plate collector when considered on a day long basis. When complete with tracking mechanisms (which must withstand hurricane force winds), collectors with even modest concentration ratios of 3-10 times are considerably more costly per unit energy collected than are the flat plate collectors (Daniels, 1964).

Because of their relatively low cost and their ability to collect diffuse as well as beam radiation, flat plate collectors are the work horses of the solar industry. Even though variations (Fig. 13) are manufactured which use air as a heat transport fluid, we will confine our consideration to those units through which a liquid circulates (Fig. 14).

The heart of the flat plate collector is the heat deck.

Flat plate collectors operate at low temperature (180° F) and are usually constructed with metal heat decks of copper, aluminum or steel. Very low temperature heat collectors (ca. 90° F) used for swimming pool heating sometimes utilize plastic heat decks. Large areas are required for adequate pool heating and unglazed plastic collectors are less expensive than conventional flat plate collectors (Root, 1960). So, economic considerations favor the use of the cheaper un-insulated, uncovered plastic pool heaters, but their useful life is yet unknown.

In the low temperature (180°F) collectors, copper, aluminum and steel decks all function satisfactorily from a thermal standpoint. Each metal may be darkened with organic coatings or electrically deposited coatings with equal ease so the choice of deck material involves evaluating its resistance to corrosion, the ease with which it may be fabricated, and its relative cost. Some heat decks contain fluid passages which are an integral part of their fabrication. Aluminum cooling panels in refrigerators are an example of this type of construction. Heat decks with integral passages are fashioned from all three metals. Most often their thickness is determined not by fin design considerations but by the tube wall thickness required to withstand the working and test pressures encountered in the tubular passages. Because the passages are often four or more in apart, this results in high material costs because of the thicker-than-necessary webs between the passages. On balance, aluminum decks of this type cost about one third as much as 100% copper decks.

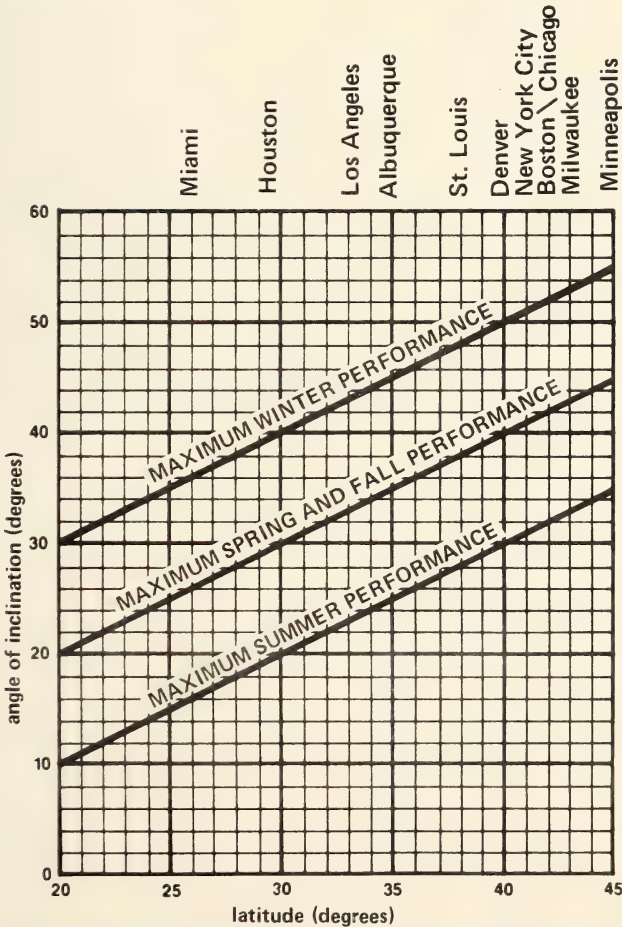


Fig. 12. Recommended elevations for flat plate heat collectors at various latitudes (after Partington, et al., 1976).

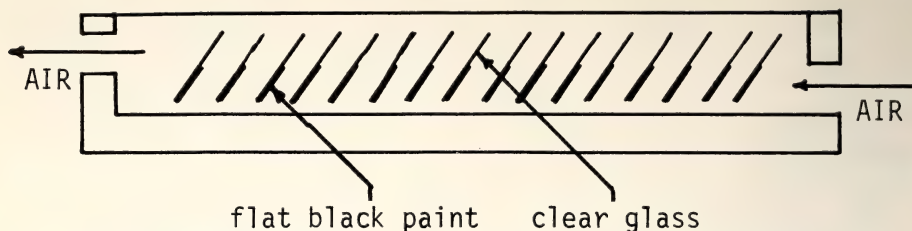


Fig. 13. Cross-section of a solar collector for use with air as the heat collecting fluid.

The most common—and the oldest—method of fabricating heat decks involves affixing metal tubes or pipes to flat sheets of metal. The pipes may be soldered to the sheet continuously or intermittently, clamped to the sheet or bonded to the sheet with thermally conductive adhesives.

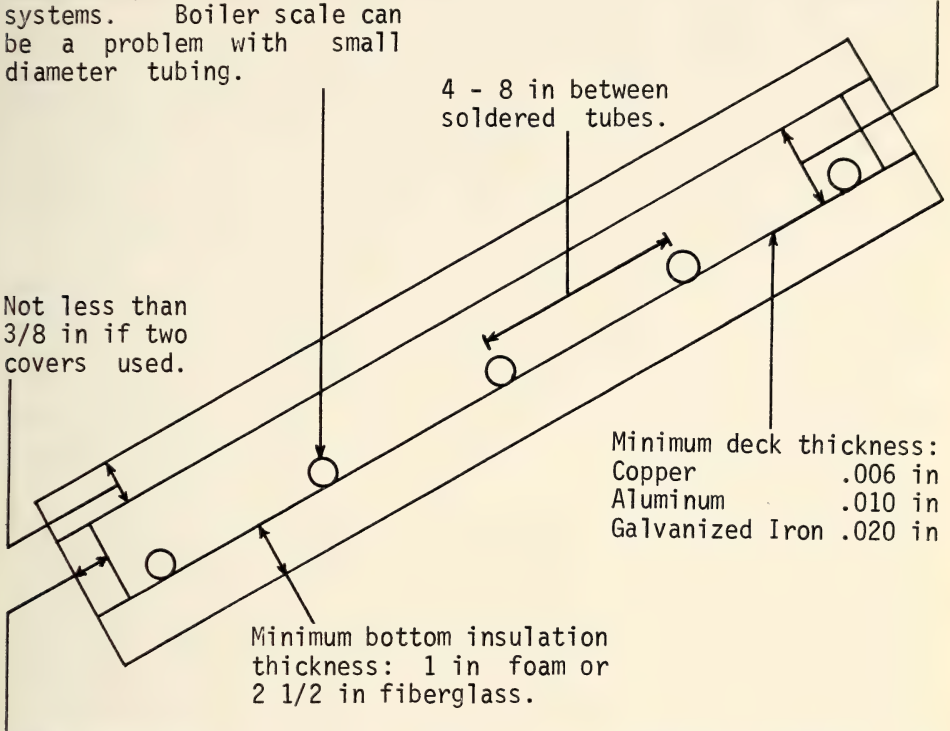
If the tubes are soldered to the sheet, copper is the material of choice for both the deck and tubing. Even though copper is expensive on a per pound basis, it is easy to solder, accepted for contact with potable water by all known code jurisdictions, corrosion resistant and it is an excellent heat conductor. The fact that it is such a good heat conductor leads Hottel (1955) to conclude that “The use of tubes spaced 6” apart in good thermal contact with a blackened copper sheet .02 inches thick (or blackened aluminum sheet .04 inches thick) is 97% as good as the extraction of heat by a completely water cooled black sheet; consequently, there is no expectation of an invention which will improve the performance of the black absorber plate.” The excellent heat conduction of copper led Hawkins (1947) to state “Thus, an absorber with 6”-8” coil spacing on 6 oz. [.008 in.] copper sheet will be 93% as efficient as an absorber with two inch coil spacing, but will cost half as much to construct per square foot of surface.” It matters little which authority is accepted in that, with good thermal contact between pipes spaced at 6 in and a relatively thin deck, above 93% of the potential heat drain from the deck is realized.

What constitutes a good thermal bond between a round tube and a flat deck? Continuous soldering is reported to be 30% better than clamping (Whillier, 1967). If thermally conductive adhesives prove to be durable when subjected to the tremendous thermal stresses encountered on solar heat decks, their thermal conductivity is about as good as that of solder (both have thermal conductivities of about 20 BTU/ (hr) (sq ft) (°F per ft). Soldering is expensive; gluing with thermally conductive adhesives is much cheaper, so if they do prove durable, their use may reduce fabrication costs. Linear cylindrical troughs stamped into the heat deck increase the contact area between round tubes and otherwise flat decks. This is highly desirable to increase heat transfer if the tubes are clamped to the decks. It is, however, unnecessary where line soldering is employed to fasten tubes and decks together. If the solder bond between the sheet and tube is as much as 1/8 in wide, the conductance of that bond is so good that the limiting heat transfer coefficient in the overall series occurs in the static liquid film on the inside surface of the containing tube (Whillier, 1964).

Figure 9 shows several styles of pipe grid being manufactured. They are all nearly equally functional thermally. The sloped grid is self-draining when vented

No smaller than 1/2 in I. D. tube except on closed loop systems. Boiler scale can be a problem with small diameter tubing.

1 1/2 - 2 in between deck and cover.



Edge insulation: 1/2 - 1 in foam. Although increasing the thickness of edge insulation reduces edge losses, it also reduces heat collection area and thus heat gains. 1/2 in of good quality foam is a rule of thumb compromise for most climates when insulating metal housing boxes.

Fig. 14. Cross-section of a flat plate heat collector indicating design parameters (after Root, 1976).

and complete internal wetting results in maximum heat transfer even if the collector is mounted slightly off level.

Soldered pipe connections within the heat collector housing box deserve special attention. The 50-50^s solder almost universally used by the plumbing industry has a yield strength of only 40 psi at 250°F. A yield strength of 200 psi can be realized by 95-5^s solder even at the higher temperature of 350°F. Unfortunately, 95-5 solder is twice as expensive as 50-50 solder (about \$14.00 per lb. retail). On balance, only 0.5-1.0 lb of solder will be required to continuously solder 100 ft of 3/4 in pipe to a 40 sq ft heat deck and sweat together the pipe joints involved. We note that a family of four will require a good quality 40-48 sq ft collector to meet most of their domestic hot water needs in most of Florida. Square, rectangular, or even triangular, pipes may be clamped to heat decks. A collector produced by a firm of national stature employs this method with a

^s50% tin, 50% lead.
^s95% tin, 5% antimony.

good measure of success. Heat transfer is further encouraged by the application of thermally conductive adhesive to the interface between the rectangular tube and the flat deck.

Because of the corrosive nature of much of Florida's drinking water, aluminum and steel tubes are seldom put into direct contact with it. More often they are employed in conjunction with heat exchangers to form a closed heat collection loop (Fig. 10). A water-glycol mixture within this loop may easily be treated with corrosion inhibitors to protect those metals with which it is in contact, or silicone oils or other non-corrosive liquids may be used for heat transport.

Because of the dilemma caused by the high cost of copper on one hand, but its good resistance to corrosion on the other, some systems have been engineered in which copper tubes or pipes are affixed to aluminum or galvanized heat decks. There are two problems to be dealt with in these cases. The coefficients of thermal expansion of these materials differ by roughly one third (steel 0.114×10^{-4} ; copper 0.166×10^{-4} ; aluminum 0.224×10^{-4}) (Perry, 1941). As a consequence of this, a 9 ft copper tube soldered to a galvanized steel deck may suffer thermal deformation or it may "work" back and forth if it is *not* continuously soldered. This "working" soon leads to reduced thermal contact between tube and deck.

A second problem with hybrid decks involves the differing positions of their metal components in the galvanic series. If moisture containing any conducting salts gets into contact with such hybrid deck systems, the potential for galvanic corrosion is great. Zinc is next to magnesium at the active or anodic end of that series, aluminum is very near the anodic end and copper is situated halfway across the scale toward the noble or cathodic end (Fontana and Green, 1967).

This is not to say that clamping should not be used nor is it to look askance at hybrid decks because of potential galvanic corrosion problems. Costs are a constant problem to those who would design or produce quality heat collectors. Everything which goes into the construction of heat decks is relatively expensive. Thus, the possibility exists that constructing them in such a way as to reduce their functional efficiency by 20% may reduce their cost by 15% or even more. In such a case, the cheaper compromise would benefit the consumer and make the unit more saleable. On balance, because of the very high cost of solar heat collectors, the use of materials or construction methods which reduce their durability is undesirable. The expectation of most responsible manufacturers of low temperature heat collectors is that their units will last at least 20 yr.

Coatings: The heat deck, regardless of its construction, needs to be darkened to function satisfactorily. Flat black paint absorbs more than 90% of the solar energy which impinges on its surface. Unfortunately, most black paints re-emit more than 90% of that energy at a relatively long wave length—3-15 microns for a 200°F deck. Because it is possible to interrupt the outflow of the long wave length energy with low iron content glass and, to a lesser extent, with some light transparent plastics (Edlin, 1958; Streed, 1974), most flat black paints function in an optically acceptable manner. The judgements involved in their selection become centered around their long term adhesion, surface durability, ease of application and cost.

For years, researchers have been investigating selective surfaces which absorb a high percentage of incident solar energy, but do not reradiate much of it even at a very long wave length. At least four methods accomplish this and they have been described in detail by Farber (1959), McDonald (1975), Merriam (1973), Tabor (1958, 1961, 1967) and Duffie and Beckman (1974). Suffice it to say that several organic coating systems have been developed which exhibit some degree of selectivity and some collectors being marketed are being coated with them. Numerous electroplated selective coating systems have been developed. Heat decks with surfaces which have been electrolytically produced are being marketed by several manufacturers. At least one collector manufacturer is marketing a unit which is coated with a semi-conductor system which functions as a thermal diode.

If selective coatings have shortcomings, they are related to their high cost and some questions regarding their long term weatherability. Their ability to reduce reradiation of heat energy is a major advantage and will be examined from a slightly different standpoint in subsequent paragraphs which deal with transparent coverings.

Insulation and Housing: Even though the heat deck is the functional part of a flat plate collector, the naked heat deck will not serve us well. If placed in the sun, it will come to equilibrium with its surroundings at a temperature not usefully above ambient.⁷ Additionally, an unprotected metal heat deck may be damaged by weathering in a short time. However, if it is surrounded on the back and sides with insulation and covered with a weatherproof, light transparent surface, it will retain much more of the energy which strikes its surface and it will be protected from weathering.

Insulating materials for flat plate heat collectors should have several qualities in addition to good insulating characteristics. If, for some reason, no fluid is flowing to drain heat away from the heat deck, it may rise to a very high temperature on a warm sunny day. The insulating material must not break down at these temperatures of 300°-350°F. Some problems along these lines have been encountered with freon blown polyurethane foams used in heat collectors. On occasion they have expanded irreversibly and their expansion has damaged collectors (*Engineering News Record*, Nov. 20, 1975). Good high temperature tolerance of CO₂ blown polyurethane foam has been reported (Moore, 1974). In some instances, polyurethane has out-gassed a low molecular weight material which has recondensed on the inside of the transparent collector cover and cut down its solar transmittance. Water vapor in contact with very hot urethane foam surfaces can react with the chloroflouro hydrocarbon foaming gas to produce hydrofloric and hydrochloric acid.

However, freon blown polyurethane is a readily available, relatively inexpensive, material with superior insulating qualities. When it is used in heat collectors, care should be exercised to separate it thermally from the potentially

⁷The use of uninsulated, uncovered swimming pool heating decks is in apparent conflict with this statement, but during the swimming season ambient temperatures often exceed pool temperatures.

very hot heat deck surface. An air gap will accomplish the desired thermal uncoupling.

The isocyanurate foams are alleged to provide the same insulating qualities as polyurethane at about the same price—\$0.31 per sq ft for 1 in foam sheets. No known field tests made on the isocyanurates have shown up the problems occasionally encountered with freon blown polyurethane foams.

Styrofoam will not stand the high temperatures produced when no heat is being taken off the deck, so if it is to be used it must be protected by a thermal barrier from the heat deck.

Fiberglass is very inexpensive and is an excellent insulator *when dry*. Because of the very long life expected of an expensive heat collector, it must be anticipated that constant expansion and contraction of the transparent surface may eventually cause it to leak around the edges during rain storms. If fiberglass is exposed to water, it absorbs it into its matrix by capillary action. This does not mean that fiberglass should not be used; it does mean that boxes which use such materials must be resealed periodically to prevent leakage and be provided with bottom drain holes to allow any accumulated moisture to escape.

Asbestos concrete has been used to build ground mounted heat collector boxes in Australia for years (CSIRO, 1964). Its use offers the opportunity for the construction of inexpensive large common containers in which arrays of collector decks for building heating and cooling may be deployed.

With the exception of asbestos concrete, all the insulating materials mentioned require that a box be constructed to house them. The box provides structural support for the heat deck and insulation and protects both from the weather. For years, 18 to 24 guage galvanized iron or aluminum have been used for boxes for heat collectors (Hawkins, 1947). They are strong and durable. They may be painted and they are easy to work with and form. Unfortunately, these metals are also excellent heat conductors, so any energy which escapes through the insulation or through bolts used to anchor the deck in place is immediately lost to the atmosphere.

As a consequence of this shortcoming of metal boxes, several manufacturers are using plastic heat collector boxes or combination plastic-metal boxes. Fiberglass reinforced polyester resin may be used in this manner as long as it is remembered that any unreacted polyester resin may out-gas if the inside surface of the box reaches very high temperatures. At least one manufacturer uses an ultra-violet shielded plastic extrusion in combination with several insulating materials to create a strong, durable box with no exposed metal parts except glazing battens.

Whatever its basic construction, the chief role the box serves is to house the deck and its insulation and protect them from the weather. If it can be made to provide additional insulation without losing significant durability or strength, so much the better. Once the heat deck is insulated and housed, the transparent cover material must be selected. In accordance with the greenhouse effect, solar radiation will pass through glass but long wave length heat radiation from the hot deck will not (Fig. 15). That is only half the story, unfortunately. While long wave length radiation won't pass through the glass, it is absorbed by it and this

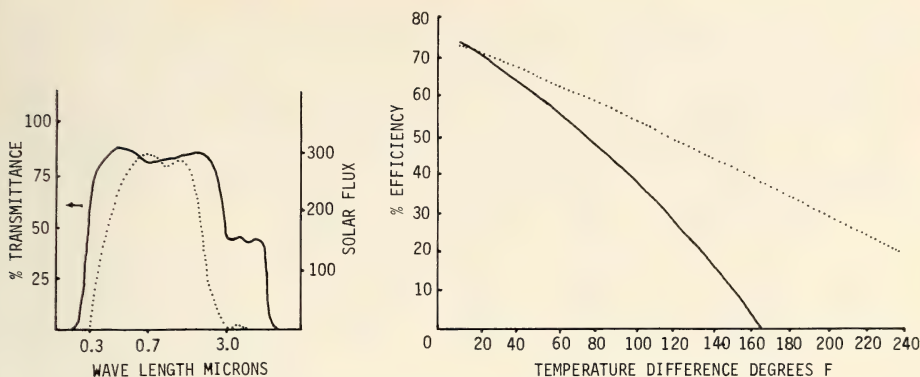


Fig. 15 (left). Conceptual drawing illustrating the greenhouse effect. The solid line indicates percent transmittance of glass vs. wave length of light; the dotted line indicates energy distribution of the solar spectrum with a solar flux expressed in BTU per hr per sq ft vs. wave length of light.

Fig. 16 (right). Flat plate collector efficiency vs. temperature difference between the outer glass and the absorber for selective (dotted line) and conventional (solid line) black coatings at a solar flux of 237 BTU per sq ft per hr (after Lorsch, 1973).

absorption heats the glazing pane. The outside surface of the hot pane is in contact with the ambient air and it loses heat by the mechanism of upward convection—and reradiation to the sky under clear conditions. The effective temperature of a clear daytime sky is reported to be ambient temperature–10°F (Whillier, 1967). Since water does not normally flow through the heat collector at night, the fact that the effective night sky temperature is thought to be–100°F^a for purposes of radiation loss calculations, is of no great concern except in the case of freezing conditions. Under no wind, clear sky conditions, flat plate collectors are reported to have frozen upon rare occasions at air temperatures of 38°–40°F!

By whatever series of mechanisms, if the heat deck radiates heat to the transparent cover, some of that heat is going to be lost to the atmosphere. This is why selective coatings have a distinct advantage over nonselective coatings. They do not reradiate nearly as badly as their nonselective cousins, so selectively coated decks allow heat collectors to be operated at high temperatures with low losses (Fig. 16). Some efforts have been made to coat glass and transparent plastic surfaces to make them selectively reflect long wave length heat radiation rather than to absorb it (Johnson et al., 1975). The procedure also reduces reradiation losses.

Of course, internal convection transfers some heat from the heat deck to the transparent cover and selective surfaces do not help solve this problem.

The internal convection problem is being attacked in several ways. At least two major glass manufacturers are making evacuated tubular glass heat collectors. In even a partially evacuated tube there is little convection loss. The system works fine but the costs range up to \$70 per sq ft of collector surface. Another approach to reducing internal convection is being tried. Flat plate collectors are being fitted with honeycombs to break up the air space separating heat decks from transparent surfaces into small cells. This method reduces convection

^aFigure used to predict freeze damage by Florida Citrus Experiment Station at Lake Alfred, Florida.

losses. At this time there are no systems of this type thought to be economically competitive in terms of dollars of collector cost per BTU collected.

A second glass cover is sometimes added to reduce upward losses from flat plate heat collectors. Although, the second cover doubles the glass cost and causes an additional reflective loss of 8% of the incoming radiation (Robinson, 1955), it is required if flat plate collectors are to produce 140° water north of about the latitude of Gainesville, Florida, in cold weather.

Figure 14 shows satisfactory cover to deck spacing for both single and double glazing (Hottel and Woertz, 1942; Lorsch, 1973).

Glass is heavy, expensive, hard to hold in place and difficult to keep water tight. It sometimes suffers thermal breakage in flat plate heat collector applications. Hail breaks untempered glass and even tempered glass is subject to breakage when hit with heavy objects. Except for its transparency to solar radiation and its opacity to heat radiation, its characteristics make it less than ideal as a glazing for flat plate heat collectors.

Some transparent plastics are cheap, durable, not subject to breakage and easy to hold in place. Unfortunately, most of them have disadvantages along with the stated advantages. Tedlar is cheap (10¢ per sq ft for 4 mil), can be heat shrunk (7% shrinkage) into place and does not reflect as much energy early in the morning and late afternoon as a glass surface does. But 4 mil Tedlar requires support in the form of a wire mesh grid if as much as 2 × 4 ft areas are to be spanned. Further, it is transparent to 30% of the long wave length heat radiation to which glass is opaque (Duffie and Beckman, 1974). Polycarbonates are very strong though quite expensive. Like glass, they are opaque to long wave length radiation but unlike glass they are also opaque to 5-7% of the solar spectrum (Kirkpatrick, 1974).

Products which contain 15%-40% fiberglass filaments bonded together with proprietary mixes of thermosetting acrylic-polyester polymers have recently been developed for use in building and greenhouse construction. The manufacturers claim their optical performance rivals that of glass and they are relatively inexpensive at 41¢ per sq ft, strong and durable (guaranteed up to 20 yrs). Many collectors now offered for sale make use of plastic-glass fiber combinations in molded or sheet form. Covers made of these materials may be molded in such a way as to overlap the sides of the heat collector box and produce a highly leak resistant joint.

The majority of heat collector manufacturers feel that 40-48 sq ft of good quality flat plate heat collectors coupled to an 80 gallon storage tank will provide for about 90% of the hot water needs of a family of four in most of Florida. A booster is located in the top 1/3 of the storage tank to provide the remaining 10%. Many of them recommend the retention and use of an existing electric hot water heater if it is relatively new (Fig. 17).

As previously suggested, most of the complete water-heating systems being offered are not of the thermosyphon type. In most of them the circulation is forced by a very low power (30 watt) electric pump. The operation of the pump is most often controlled by a differential thermostat. This system keeps the heavy

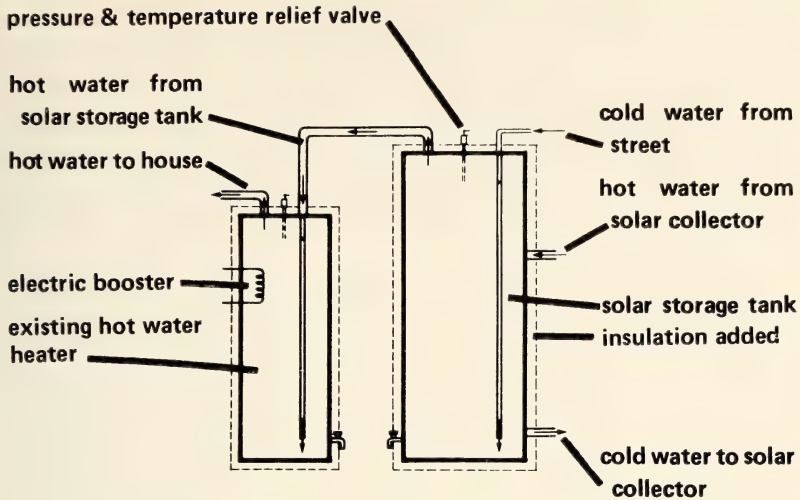


Fig. 17. A two tank storage system using an existing water heater as an auxiliary booster (after Partington, et al., 1976).

tank down at ground level where it's easier to support and where leaks are not as harmful when they finally develop. The heat collector may still be placed on a sunny south facing roof where it's fairly well protected from accidental breakage and shading.

OTHER APPLICATIONS—Solar water heaters are still expensive. So are solar building heating systems. Solar air conditioning systems are not yet offered as complete units. Arkla does produce a limited number of lithium bromide-water absorption units modified for use with 190° – 220° water or steam. Private industry has made great strides in redeveloping manufacturing capability in the solar water heating field in the few years since the oil embargo made us aware of the fragility of America's energy supply sources. As energy reserves dwindle further, Florida may suffer more than many other states since virtually all of her fossil fuel supplies must be shipped in. When energy costs rise, shipping costs rise and the combination will move the state in an unenviable position. Hopefully, industry, agriculture and citizenry all will be able to use some of the abundant Florida sunshine to alleviate the economic pressure.

As the state's population continues to grow, a shortage in another area is likely to occur. Florida's fresh water supply is limited. Salt intrusion in deep wells near the coasts, loss of recharge areas to urban sprawl and pollution of the aquifer are becoming more serious problems as the population increases.

Solar Stills: Here, too, solar energy may offer a partial solution. Florida has an abundance of very humid air—especially during the summer when demands on the water supply are apparently at their maximum. Solid absorbents like calcium chloride and liquid ones like the glycols may be allowed to absorb nocturnal moistures from the air and that moisture may be recovered by heating the absorbent with solar energy during the daylight hours. A slight modification

of this scheme was used in 100 BC in Theodosia, Crimea. Nocturnally cooled rock piles were used to collect dew which was piped to common watering spots through sandstone pipes (Daniels, 1964).

Conventional solar stills were used to produce all the fresh water for the Chilean nitrate mines near Las Salinas from 1872 to about 1910. The 51,000 sq ft of glass-tented shallow tanks supplied about 6,000 gallons of fresh water per day for nearly 40 yr. The rate was about a lb per sq ft of tank and the solar efficiency was about 33%.

Animal and plant life being totally dependent on usable water, it is not surprising that considerable scientific effort has been devoted to the development of solar stills. Maria Telkes presented a report on them to the World Symposium on Solar Energy in 1955 (Telkes, 1956). During the mid-fifties, Edlin, Löf, Strobel and a team from Batelle Memorial Institute headed originally by Locklin combined efforts to study the subject at a thoroughly instrumented large facility at Ponce de Leon inlet (Strobel, 1957; Bloemer, et al., 1964). In 1970, a "Manual on Solar Distillation of Saline Water" was prepared by members of that team and others who had joined them in the ensuing 15 yr (Talbert, et al., 1970). During 1970-71, a power-food-water complex was constructed near Abu Dhabi on the Persian Gulf by scientists from the University of Arizona Energy Research Laboratory (Univ. of Arizona 1970-71 Annual Report). Several articles have appeared recently in *Solar Energy* on similar themes.

A typical solar still is depicted in cross-section in Fig. 18. The transparent cover may be glass or plastic but its inside surface should be treated so that the condensing film will not "bead" on the surface (Daniels, 1964). The cover may be attached to a rigid frame or it may be inflated like a sausage skin with a small pump. Farrington Daniels, another pioneer in solar distillation, devotes a full chapter to the subject in his book "Direct Use of the Sun's Energy" (1964).

A novel approach to improving the efficiency of solar stills with heat pipes is shown in Fig. 19 (Lowe, 1975). Output of distilled water was reported to be increased from 3 l per sq m to 5 l per sq m in the heat pipe system. The still in the sketch was developed by Dornier in Germany.

The main problem with using solar energy to distill water is that because solar flux density is low, large expensive areas are required to harvest enough energy to produce useful quantities of water. But, as conventional energy costs rise, the amortization period of solar equipment is reduced.

Solar Greenhouses: Florida receives about one third of her income from agricultural and farming activities so applications of solar energy which may benefit those areas deserve consideration. Crop drying is an important application of solar energy in the corn and wheat producing states but it does not consume enough energy in Florida to be of primary interest. Protection of ornamental plant nurseries during freezing weather does, however. John's Nurseries, the largest independently owned commercial plant grower in Florida used \$140,000 worth of fuel at a cost of \$.0104 per sq ft of greenhouse space to prevent frost damage during the 1975-76 cold season (Robert Scott, personal communication).

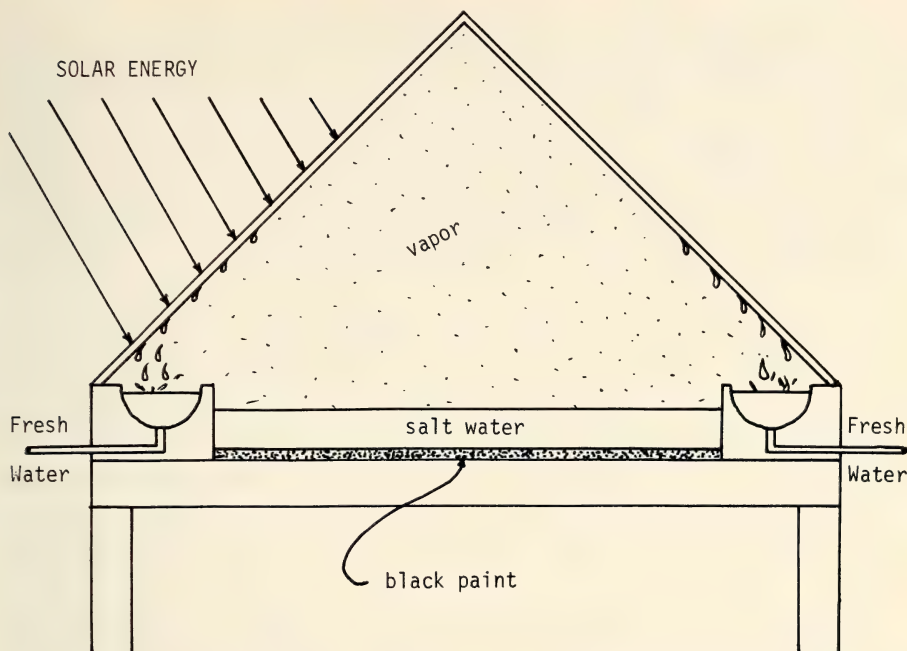


Fig. 18. A solar still in sectional view. (Redrawn from a pamphlet titled "Sea Water Conversion" from the Solar Research Station, Daytona Beach, Florida, of the Office of Saline Water, U. S. Dept. of Interior, Unnumbered and undated.)

Innovations in solar greenhouse design were discussed in this Symposium by Sheppard and Williams whose paper follows in this issue of the *Florida Scientist*. Even as far north as Canada, energy conserving greenhouse structures are being evaluated (Lawand et al., 1975). The ornamental plant and glasshouse vegetable industries stand to benefit substantially from new developments in this field.

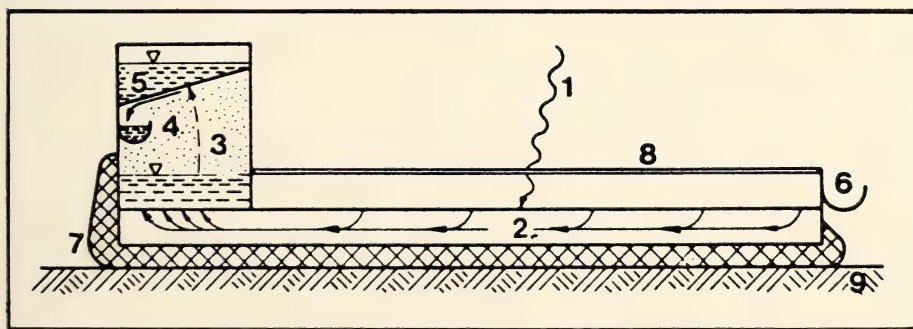


Fig. 19. High output solar distillation system. 1) Incoming energy; 2) heat pipes transmit energy from the heat deck to the evaporation chamber much more efficiently than a copper conduction; 3) evaporation chamber with vapor rising from heated brine; 4) collector channel for distilled water; 5) cool brine water enhances condensation and is preheated prior to admission to the evaporation chamber; 6) rainwater trough; 7) insulation layer; 8) glass cover; and 9) supporting substrate (after Lowe, 1975).

Solar Pumps: Proper control of water level is important to farmers and ranchers using the vast flatlands of the central and southern parts of the state. During drought, water is pumped from irrigation canals into the fields and in flood times, water is discharged from the fields to canals. Operation of those pumps is becoming an increasingly heavy economic burden to their users. Perhaps more important, however, is the fact that shortages may develop and fuel deliveries be interrupted. This could have disastrous results for farmers and nurserymen alike and result in short supplies of several fruits and vegetables for the everyday housewife.

Solar water pumps were in use in many parts of the world during the late 1800's and early 1900's (Jordan and Ibele, 1955). In 1698, Thomas Savery was granted a patent (in England) for a low head steam operated pump in which the only moving parts were three valves. As early as 1961 Jenness suggested several modifications of the Savery water pump which allow it to operate on solar energy (Jenness, 1961). Because of the remoteness of some pumps on large ranches operating them with solar energy could save countless hours of man power as well as the transportation of more conventional fuels and operating costs.

Other Uses: Low temperature industrial process heat can be produced with air heat collectors pictured in Fig. 13. As energy costs escalate, those industries which are able to adjust their production cycles to take advantage of solar energy will doubtless be doing it. The WIX air cleaner distributor in Central Florida has already switched from electrically heated air to solar heated air for drying re-washed carburetor air filters for large trucks. Some of them cost as much as \$140.00 new and can be washed two or three times at a cost of about \$10.00 before they require replacement (John Newsom, personal communication, 1976).

From a broad view point the practical application of solar energy in Florida includes thermal, mechanical and agricultural applications. Some marine biologists feel that because of the vast estuarine areas which border Florida's coast line, solar applications in these fields may improve the per acre production of edible marine life. Who knows what breakthroughs will come next as experts in the many academic disciplines apply their knowledge to the practical application of solar energy?

OUTLOOK—As mentioned, the federal government which spent less than \$100,000 a year from 1950 to 1970 on solar research (Hughes, 1974), spent 86 million last year and will spend over 250 million in fiscal 1976. Much of that 250 million will be spent on demonstration projects. Their purpose is to establish the technical and economic feasibility of heating and cooling buildings. There is a role for the scientific community in the demonstration area. Advisors and trouble shooters will be needed by industrial contractors to guide them in the construction of and operation of their projects.

A considerable amount of federal money will be spent on pure and applied research primarily by HUD, FEA, ERDA and DOD. For the first time in the history of industrial research in the United States, solar research is receiving substantial private funding.

The problem of establishing thermal test procedures and rating methods has been addressed (Hill and Kusuda, 1974). Solar scientists are debating the suggested methods, as indeed they have been since as early as the 1950's (Robinson and Stotter, 1959; Whillier and Richards, 1961).

The test problem is intensified by the fact that there are a very limited number of facilities in the entire nation which are equipped to perform thermal testing. Some scientists point out that the consumer is interested in the annual savings which accrue as a result of his investment in solar equipment. They raise the fundamental question of whether a performance rating derived from data taken in November in Arizona relates to the performance of the unit on a year round basis in St. Petersburg, Florida (Lior, 1974).

The concept of locational flexibility for the testing of units has been given impetus by the development of a mobile thermal test facility at Florida Technological University (Nimmo and Larsen, 1976). This concept holds considerable promise and may serve to overcome objections raised by Dr. Lior.

A heavy responsibility is placed on the scientific community by the paucity of American research activity which occurred during the 1960's. Solar literature is only marginally complete in most university libraries and much of it is in microfilmed form. This leads to the tendency on the part of some researchers to slight the study of past research achievements which usually precedes the selection of research topics to be pursued. Fortunately, the University of New Mexico recently published through its Technology Application Center a bibliography entitled "Solar Thermal Utilization 1957-1974". The two volume set lists, with abstracts, some 4,000 works published during that period. They are indexed by subject, by author, and by title and offer quick reference to much useful solar literature (Leffler, 1974). Surprisingly enough, the cost (\$37.50) of this bibliography is modest enough so that it is subject to inclusion even in private libraries.

No responsible student of energy consumption makes any claim that the use of solar energy is going to drastically reduce the nation's dependence on fossil fuels. Even optimistic estimates suggest that only 10% of our fuel needs may be met by solar devices by 1999 (Wilhelm, 1976).

What the practical application of solar energy does have to offer is economic relief for the average homeowner, Table 3. The sun's energy is an on-site utility provided free by nature. It doesn't have to be transported in supertankers or even in trucks or trains. It need not be delivered over costly electrical distribution networks. It simply needs to be captured and stored in accordance with a technology which has been thoroughly explored and reported on during the period since 1900.

Future advances in that technology will probably take the form of economies which can be exercised through the use of new materials and new fabrication techniques. Those economies are badly needed if solar systems are to be priced within the budgets of those who need them most—middle and lower income families.

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LITERATURE CITED AND BIBLIOGRAPHY

- ABBOT, C. G. 1934. *The Sun and the Welfare of Man*. Smithsonian Instit. Ser. Vol. 2. New York.
- _____. 1939. Utilizing Heat from Sun. Smithsonian Misc. Coll. Publ. 353. Vol. 98 (5). March 30.
- ALT, H. L. 1935. Sun effect and the design of solar heaters. *Heating-Piping and Air Conditioning* Feb. 1935:111-118.
- BECKER, C. AND J. BOYD. 1957. Solar radiation availability on surfaces in the United States as affected by season, orientation, latitude, altitude and cloudyness. *Solar Energy* 1(1):13-21.
- BLISS, R. W., JR. 1956. Solar house heating, a panel. Pp. 151-158. *In Proc. World Symp. Applied Solar Energy*, 1955. Stanford Res. Instit. Menlo Park.
- _____. 1961. Atmospheric radiation near the surface of the ground: a summary for engineers. *Solar Energy* 5(3):103-120.
- BLOEMER, J. W., J. R. IRWIN AND J. A. EIBLING. 1964. Design of basin-type solar still. Res. and Develop. Progr. Rept. 112. Office of Saline Water, U. S. Dept. Interior. Washington, D. C.
- BROOKS, F. A. 1936. Solar Energy and its Use for Heating Water in California. *Agric. Exper. Sta. Univ. California Bull.* 602.
- _____. 1952. Atmospheric radiation and its reflection from the ground. *J. Meteorology* 9 (1, Feb.):41-52.
- CARNES A. 1932. Heating water by solar energy. *Agric. Engin.* 13 (6):156-159.
- COTTONY, H. V., AND R. S. DILL. 1941. Solar Heating of Various Surfaces. *Building Materials and Structures. Nat. Bur. Standards Rept. BMS 64.* Jan. 23.
- CSIRO. 1964. *Solar Water Heaters, Principles of Design, Construction and Installation*. Commonwealth Sci. Industr. Res. Org. Australia. 16 pp. Melbourne.
- DANIELS, F. 1956. The sun's energy. Pp. 19-26. *In Proc. World Symp. Applied Solar Energy*, 1955. Stanford Res. Instit. Menlo Park.
- _____. 1964. *Direct Use of the Sun's Energy*. Yale Univ. New Haven. (by arrangement Ballantine Books of Random House. New York.)
- DUFFIE, J. A., AND W. A. BECKMAN. 1974. *Solar Energy Thermal Processes*. John Wiley & Sons. New York.
- EDLIN, F. 1958. Plastic glazing for solar energy absorption collectors. *Solar Energy* 2 (2):3-6.
- ENGINEERING NEWS RECORD. 1975. Too much heat causes school's solar collectors to fail. *McGraw Hill. Issue Nov.* 20:14.
- ERDA-75. 1975. *Catalog on Solar Energy Heating and Cooling Products*. Energy Res. Develop. Administr. Techn. Info. Ctr. (P. O. Box 62). Oakridge, Tennessee.
- ERICSSON, J. 1884. The sun motor and the sun's temperature. *Sci. Amer. Suppl.* 17:6727.
- FALTERMAYER, E. 1976. Solar energy is here, but it's not yet Utopia. *Fortune* 93 (2, Feb.):103-116.
- FARBER, E. A. 1959. Selective surfaces and solar absorbers. *Solar Energy* 3(2):9-13.
- _____. 1975. Unpublished lecture before the Associated Plumbing and Mechanical Contractors of Florida Solar Conference. Orlando, Jan., 1975.
- _____. F. M. FLANIGAN, L. LOPEZ AND R. W. POLIFKA. 1966. Operation and performance of University of Florida solar air-conditioning system. *Solar Energy* 10(2):91-95.
- FARRALL, A. W. 1929. *The Solar Heater*. *Agric. Exper. Sta. Univ. California Bull.* 469.
- FEDERAL ENERGY ADMINISTRATION. 1973. *Solar Collector Manufacturing Activity*. GPO 896-829:1-11.
- FONTANA, M. G., AND N. D. GREENE. 1967. *Corrosion Engineering*. McGraw Hill. New York.
- HARRENSTIEN, H. P. 1976. Unpublished lecture before ASME Solar Energy Seminar, West Palm Beach, Florida. Jan. 1976.
- HAWKINS, H. M. 1947. Domestic Solar Water Heating in Florida. *Florida Engin. Ind. Exper. Sta. (Gainesville) Bull.* 18:1-26.
- HILL, J. E., AND T. KUSUDA. 1974. Method of Testing for Rating Solar Collectors Based on Thermal Performance. Interim Rept., Nat. Bur. Standards 74 635:1-37; 11 fig.
- HOTTEL, H. C. 1956. Residential uses of solar energy. Pp. 103-112. *In Proc. World Symp. Applied Solar Energy*, 1955. Stanford Res. Instit. Menlo Park.
- _____. 1976. A simple model for estimating the transmittance of direct solar radiation through clear atmospheres. *Solar Energy* 18(2):129-134.
- _____, AND J. B. HOWARD. 1971. *New Energy Technology—some Facts and Assessments*. Massachusetts Instit. Techn. Press. Cambridge.
- _____, AND B. B. WOERTZ. 1942. The performance of flat plate solar heat collectors. *Trans. Amer. Soc. Mech. Engin.* 64:91-104.

- HUGHES, P. S. 1974. Review of Selected Federal and Private Solar Energy Activities. U. S. General Accounting Office Rept. B 178726:1-40.
- JENNESS, J. R., JR. 1961. Some consideration relative to a solar powered Savery water pump. *Solar Energy* 5(2):58-60.
- JOHNSON, T. E., S. WELLESLEY-MILLER, D. CHAHROUDI, J. BROOKS, S. WAGNER, C. HEESCHEN AND D. BRYAN. 1975. Chpt. 4.3 Drude Mirrors. Pp. 36-40. *In* Exploring Space Conditioning with Variable Membranes. Dept. of Architecture, Massachusetts Inst. of Techn. Cambridge.
- JORDAN, R. C. AND W. E. IBELE. 1956. Mechanical energy from solar energy. Pp. 81-101. *In* Proc. World Symp. Applied Solar Energy, 1955, Stanford Res. Instit. Menlo Park.
- KIRKPATRICK, D. L. 1974. Solar collector design and performance experience for the Grover Cleveland School, Boston, Mass. Pp. 26-32. *In* Proc. Nat. Sci. Found. Workshop on Solar Collectors for Heating and Cooling of Buildings. New York. Nov. 1974.
- LAWAND, T. A., R. ALWARD, B. SAULNIER AND E. BRUNET. 1975. The development and testing of an environmentally designed greenhouse for colder regions. *Solar Energy* 17:307-312.
- LEFFLER, J. (Technical Coordinator) 1974. Solar Thermal Energy Utilization 1957-1974. A Bibliography with Abstracts. Techn. Application Ctr. Univ. New Mexico, Albuquerque.
- LIOR, N. 1974. Solar collecting testing and standards. Pp. 349-358. *In* Proc. Nat. Sci. Found. Workshop on Solar Collectors for Heating and Cooling of Buildings. New York.
- LIU, B. Y. H., AND R. JORDAN. 1967. Availability of Solar Energy for Flat Plate Collectors in Low Temperature Engineering Applications of Solar Energy. Amer. Soc. Heat Refrig. Air Cond. Engin. New York. Pp. 1-18.
- LÖF, G. O. G. 1956. Solar house heating, a panel. Pp. 131-145. *In* Proc. World Symp. Applied Solar Energy, 1955. Stanford Res. Instit. Menlo Park.
- . 1974. Space heating with solar air collectors. Pp. 92-98. *In* Proc. Nat. Sci. Found. Workshop on Solar Collectors for Heating and Cooling of Buildings. New York.
- LORSCH, H. 1973. Performance of flat plate solar collectors. Pp. 1-14. *In* Proc. Solar Heating and Cooling for Buildings Workshop, Washington, D. C., March 1973. Publ. No. P. B. 223536. Distr. by Nat. Techn. Info. Service. U. S. Dept. Commerce. Washington, D. C.
- LOWE, J. F. 1975. Silent solar-powered desalinization plant. *Design News* Dec. 8:84.
- MANGON, M. H. 1880. New results on the utilization of solar heat at Paris. *Comptes Rendus* 91:388.
- MCDONALD, G. E. 1975. Spectral reflectance properties of black chrome for use as a solar selective coating. *Solar Energy* 17 (2):119-122.
- MEAN DAILY SOLAR RADIATION, MONTHLY AND ANNUAL. 1964. United States Dept. of Comm., Weather Bureau. Library of Congress #G3701.C83. Available from Supt. of Documents, U. S. Govt. Printing Office. Washington, D. C. 20402.
- MERLE, A. 1940. Solar heaters for service water. *Heating and Ventilating*. Aug. 1940:22-26.
- MERRIAM, M. E. 1973. Materials technology for flat plate steam generators. Pp. 17-20. *In* Proc. Solar Heating and Cooling for Buildings Workshop, Washington, D. C., Rept. NSF/RA/N-73-4. Distr. Nat. Techn. Info. Service. U. S. Dept. Commerce, Washington, D. C.
- MOON, P. 1940. Proposed standard solar radiation curves for engineering use. *J. Franklin Inst.* 230: 583-618.
- MOORE, S. W. 1974. Structurally integrated steel solar collector development. Pp. 55-67. *In* Workshop on Solar Collectors for Heating and Cooling of Buildings. New York.
- NATIONAL SCIENCE FOUNDATION. 1973. Proceedings of the Solar Heating and Cooling for Buildings Workshop. NTIS No. PB223 536. Washington, D. C.
- . 1974. Proceedings of the Workshop on Solar Collectors for Heating and Cooling of Buildings, New York.
- NIMMO, B. AND T. LARSEN. 1976. Development of a mobile solar testing and recording "STAR" System. *In* Proc. Compleks Internat. Conf. on Helio Technique and Development, Dhahran, Saudi Arabia, Nov., 1975 (*in press*).
- PARTINGTON, W. M., D. E. ROOT, W. BARADA, J. MCCABE, W. GANTT AND S. WHIGHAM. 1975. How To Build a Solar Water Heater. Environmental Information Center. (935 Orange Ave.) Winter Park, Florida 32789.
- , ———, ———, ———, ———, ———, AND ———. 1976. Build Your Solar Water Heater. Environmental Information Center. (935 Orange Ave.) Winter Park, Florida 32789 (25 pages and 43 illustrations).
- PERRY, J. H. (ed) 1941. *Chemical Engineers Handbook*. McGraw Hill, New York.
- PROCEEDINGS: Research Frontiers in Solar Energy Utilization. 1961. Washington, D. C. Solar Energy Special issue. Sept.

- PROCEEDINGS: World Symposium on Applied Solar Energy, 1955. 1956. Stanford Res. Instit. Menlo Park. (Reprinted by Centerline Corp., 401 S. 36th St., Phoenix, Ariz. 304 pp.; illustrations).
- ROBINSON, N. 1955. Solar machines. Pp. 43-61. *In Proc. World Symp. Applied Solar Energy, 1955.* Stanford Res. Instit. Menlo Park.
- _____, AND A. STOTTER. 1959. A proposed standard test code for the determination of the efficiency of solar water heaters of the flat collector type. *Solar Energy* 3(2):30-33.
- ROOT, D. E. 1960. Practical aspects of solar swimming pool heating. *Solar Energy* 4(1):23-24.
- _____. 1976. Rule of Thumb Engineering Notes for the Practical Application of Solar Energy. (© D. E. Root. Available from Associated Plumbing and Mechanical Contractors of Florida, Box 510, Lakeland, Florida; 46 pp. and illustrations).
- _____. 1976. An overview of solar energy. *Supply House Times* 19 (2):83-110.
- SCOTT, J. E., R. W. MELICHER AND D. M. SCIGLIMPAGLIA. 1974. Demand Analysis, Solar Heating and Cooling of Buildings. Solar Water Heating in South Florida 1923-1974. Phase 1 Rept. Nat. Sci. Found. (RANN). Gov. Printing Office. Washington, D. C.
- STANDARD BUILDING CODE. 1973. (Revised 1975). Southern Building Code Congress International, Inc. (3617 8th Ave. S.) Birmingham.
- STANDARD PLUMBING CODE, 1975. Southern Building Code Congress International, Inc. (3617 8th Ave. S.) Birmingham.
- STREED, E. R. 1974. A brief review of material property measurements for solar collector components. Pp. 359-368. *In Proc. Nat. Sci. Found. Workshop on Solar Collectors for Heating and Cooling Buildings.*
- STROBEL, J. J. 1957. Summary of solar distillation processes. Pp. 117-122. *In Proc. Symp. on Saline Water Conversion.* Office of Saline Water. Washington, D. C.
- TABOR, H. 1958. Solar energy research: Program in the new desert research institute in Beersheba. *Solar Energy* 2(1):3-6.
- _____. 1961. Solar collectors, selective surfaces, and heat engines. Pp. 27-34. *In Proc. Nat. Acad. Sci.* 47:1271-1278. (Reprinted in *Solar Energy*, Sept. special issue).
- _____. 1967. Selective surfaces for solar collectors. Pp. 41-52. *In* JORDAN R. (ed). *Low Temperature Engineering Application of Solar Energy.* Amer. Soc. Heat Refrig. Air Cond. Engin., Inc. New York.
- TALBERT, S. G., J. A. EIBLING AND G. O. G. LÖF 1970. Manual on Solar Distillation of Saline Water. (for Office of Saline Water, U. S. Dept. of Interior) Battelle Memorial Institute. Columbus.
- TELKES, M. 1956. Solar Stills. Pp. 73-79. *In Proc. World Symp. Applied Solar Energy, 1955.* Stanford Res. Instit. Menlo Park.
- _____. 1956. Solar house heating, a panel. Pp. 147-149. *In Proc. World Symp. Applied Solar Energy, 1955.* Stanford Res. Instit. Menlo Park.
- _____. 1973. Energy storage media. Pp. 57-59. *In Proc. Solar Heating and Cooling for Buildings Workshop,* Washington, D. C. March 1973. Rept. NSF/RA/N-73-4. Nat. Techn. Info. Service, U. S. Dept. of Commerce, Washington, D. C.
- VELTFORT, T. E. 1942. Report on Solar Water Heaters. Copper and Brass Res. Assn. New York.
- WETHERINGTON, T. I., JR. 1975. P. 12. Is solar heat for you? *In Electric Florida.* Nov.-Dec., 1975. Electric Council of Florida.
- WHILLIER, A. 1964. Thermal resistance of the tube plate bond in solar heat collectors. *Solar energy* 8(3):94-98.
- _____. 1967. Design factors influencing collector performance. Pp. 27-40. *In* JORDAN, R. (ed.) *Low Temperature Engineering Application of Solar Energy.* Amer. Soc. Heat. Refrig. Air Cond. Engin., Inc. New York.
- _____, AND S. RICHARDS. 1961. A standard test for solar water heaters. 7 Pp. *In Proc. United Nations Confer. on New Sources of Energy.* Rome.
- WILHELM, J. L. 1976. Solar energy, the ultimate power house. *Nat. Geographic* 149 (3, March):381-397.
- WILLSIE, H. E. 1909. Experiments in the development of power from the sun's heat. *Engineering News* 61:511.
- YELLOTT, J. I. 1973. Utilization of sun and sky radiation for heating and cooling of buildings. *ASHRAE Journal* Dec. 1973:31-42.

THE ROLE OF THE FLORIDA SOLAR ENERGY CENTER IN SOLAR ENERGY SYSTEMS RESEARCH AND COMMERCIALIZATION

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ABSTRACT: *The Florida Solar Energy Center was established in 1975, pursuant to legislative directive in 1974, with authorization to conduct research, disseminate information, and develop demonstration projects relating to solar energy utilization in Florida. Under the State Board of Regents, the Center is developing and conducting a variety of programs in research, development, demonstrations, education, information dissemination, and energy systems analysis. Federal research programs in solar energy are related to the programs of the Center and have impact upon the work pursued there. The congressional mandate for establishing a national solar energy research institute has resulted in both optimism and intense proposal effort within Florida to have that research institute headquartered within the state. The Solar Energy Center interacts with a task force appointed by the Governor of Florida which has responsibility for preparation of the state's proposal. Utilization of solar energy is possible in a variety of ways. Some end uses of solar energy are technologically feasible now; some systems are approaching economic feasibility in comparison with other forms of energy; and some systems require significantly more research to establish their feasibility. Commercialization of solar energy will proceed at a rate consistent with the progress in research and development for advancing systems feasibility. As solar energy technology advances, the Solar Energy Center will continue programs of current information dissemination and training. The Center is promoting and coordinating this effort in Florida and is directly involved in research and development work with support and participation from many other organizations and individuals.*

MEASURED in terms of traditional energy sources of our society, Florida has been an energy-poor state. There are few petroleum reserves in the ground, no coal reserves, and the state's geography is not suited to hydroelectric generation. Florida, then, has imported energy to develop, maintain, and expand its level of industrialization.

While it also is true that the entire United States has produced less energy than consumed in recent years and therefore also has imported energy, mostly in the form of petroleum, Florida's record for net imports of energy exceeds that of the U. S. as a whole. In December, 1975, for example, while the U. S. was importing (from outside U. S. territories) just over 38% of the oil consumed, Florida in the same period was importing (from outside U. S. territories) in excess of 50% of its oil. There should be no surprises, then, in observing that Florida's economy will continue to be sensitive to the international costs and availability of oil (not to mention the same vulnerabilities to costs of domestic energy which are imported across the state line).

There is now recognition that oil, gas, and coal, our traditional energy sources, will not last forever. Indeed, they will last only a few years past the turn of the century if we continue with our present trends in energy consumption. Our nation has commenced serious studies in a search for alternative energy sources—either sources which are renewable, or sources which because of their quantity are nondepletable within large time frames.

Looking now at the brighter side, it may be that Florida can become less dependent upon energy controlled outside the state and, perhaps, energy-rich. Florida has two significant sources of energy—an abundance of sunshine and surrounding oceans whose surfaces act as giant collectors of solar radiation.

The Legislature of the State of Florida acknowledged solar energy as a resource much sooner than most other state legislatures. It directed in 1974, in Senate Bill No. 721, that plans be prepared for establishing a state solar energy program for the purpose of bringing about reduced reliance upon imported energy to maintain an acceptable lifestyle for the people of Florida. Responsibility for planning the solar energy program was assigned to the State Board of Regents. As prescribed in legislation for planning, a Center was to be established with the following functions:

- Develop and participate in solar-related demonstration projects.
- Develop solar energy systems, with emphasis on incident solar energy applications.
- Develop methods for testing solar equipment.
- Develop and disseminate information and maintain an information system on solar energy and solar products.
- Provide technical assistance to state agencies and manufacturers in the development of information and standards.
- Provide technical assistance to architects, builders, and others in solar energy technology application.
- Provide facilities and support for personnel from universities and research institutions within the state.
- Provide the capability to actively seek federal and other funds to support its work and coordinate cooperative solar energy research efforts within the state.
- Provide ongoing educational services for persons desiring solar energy technical knowledge at all levels of competence.

A plan was prepared in the office of the Board of Regents in 1974-75, and implementation was begun in the spring of 1975. The newly created Florida Solar Energy Center was placed directly under the jurisdiction of the Board of Regents (BOR) in the State University System, with logistics support assigned to Florida Technological University (FTU).

A Policy Advisory Board, made up of representatives of a broad spectrum of groups in Florida having particular interest in solar energy, makes recommendations to the Chancellor's office on policies of operation of the Center. A Technical Advisory Committee counsels the director of the Center on matters of ongoing operations and research activities.

The selected location for the Center was a complex of four buildings in Cape Canaveral formerly used for the University of Florida's GENESYS program and later as FTU's Canaveral Residence Center. Situated at the edge of Port Canaveral and adjacent to the Canaveral Air Force Station and Kennedy Space Center, the site of the Center encompasses 20 acres. Building facilities, comprising approximately 14,000 sq ft, include offices, laboratories, a library, classrooms, and a 200-seat auditorium.

Dr. William Phillips, Coordinator of Science Programs in the BOR, and Dr. Robert Kersten, Dean of Engineering at FTU, were named acting co-directors of the Center during its start-up period while a search was undertaken for a permanent director.

ORGANIZATION OF THE CENTER—In September, 1975, Dr. Howard P. Harrenstien, Dean of Engineering at the University of Miami, was appointed director of the Center. Dr. Harrenstien's first steps in responding to the broad range of functions as conceived by the legislature were to:

Develop and staff an organization which could effectively and efficiently address the several areas of assigned responsibility.

Contact those agencies, organizations, and persons, in state or out of state, with which the Center would be cooperating or interacting on solar energy matters.

Undertake an orderly review of project activities which would establish priority of efforts at the Center.

The various functions prescribed by the legislature fall logically into three general groupings which furnished the basis for organization.

Education and information services.

Research, development, and demonstrations.

Energy systems analysis.

Delbert B. Ward, associate professor of architecture at the University of Utah prior to joining the FSEC staff, is director of the Education and Information Services Division. Dr. Gerald W. Lowery is director of the Research, Development, and Demonstrations Division. He came to the Center from the University of Texas at Arlington where he was assistant professor of mechanical engineering and project manager for Discovery '76, the first single-family residence in Texas to be solar heated and cooled. Marvin M. Yarosh, executive director of the Florida Energy Committee from 1973 to 1975, heads the Energy Systems Analysis Division.

At present the Center staff comprises 32 employees and will reach 40 within a few months. These include research scientists, research engineers, laboratory technicians, a librarian, artists, an information specialist, and secretarial personnel.

THE EDUCATION AND INFORMATION SERVICES DIVISION—Education and information are essential components of Florida's solar energy program. User understanding of information is an essential consideration in the preparation of education and information materials because solar energy applications will be undertaken within the residential, commercial, industrial, and institutional sectors of the state to the extent that they are technically and economically feasible and only to the extent that the information is understood.

There are many user categories for solar energy utilization, ranging from the homeowner to large-scale industries. Education and information services must effectively reach all user groups and therefore take many forms. Seminars, short courses, technical and "how-to" publications, newsletters, solar product information, library documents, and solar energy systems displays are among the many activities of this division.

Recognizing the importance of placing existing solar energy technology into the hands of architects and engineers who are responsible for the design of new buildings and the modification of old ones, the division has undertaken development of a major program of short courses. The plan is to identify instructors within the state's universities with knowledge in various areas of energy technology,

to assist their universities in scheduling solar energy courses of a continuing education type, and to provide printed materials, visual aids, and case studies helpful in conducting courses at the local universities. This plan would bring instruction to the state's population centers while reducing travel costs and other inconveniences which would occur if the courses were offered at the Center. The division provides additional educational services to the citizens and solar industries of Florida, including briefings and lectures on solar energy utilization, and information bulletins on solar energy programs and products.

The Center's library of over 3,500 volumes, covering a range of technical subjects and containing an extensive collection of energy-specific texts, periodicals, reports, and government documents, is available to anyone. A full-time technical librarian also is available to assist with research in the literature at the Center.

Energy-related publications are prepared and distributed at the Center. The number of such publications is growing, and publications soon will be a major effort of the division. The Center encourages the submission of manuscripts on solar energy for assistance in publication.

THE RESEARCH, DEVELOPMENT, AND DEMONSTRATION DIVISION—
This division provides technical inputs into three principal program areas of the Center.

Inducing public acceptance of energy conservation and solar energy systems through education and incentives.

Providing demonstrations of the practicality, reliability and value of solar energy systems.

Promoting an honest and healthy solar energy industry in Florida.

The RD&D Division furnishes technical support in seminars for designers and builders, contractors, lenders, legislators, and others. The seminars may be conducted by the Center or by other organizations. The Division helps to provide information on solar energy applications for homeowners, as well as design criteria and handbooks for engineers and contractors. In legislative measures relating to taxes, codes, and zoning that affect energy use, the division provides technical assistance as required.

A number of potential applications of solar energy utilization are inhibited by a lack of fundamental and applied research. It is a function of the RD&D Division to identify these areas and encourage the needed research. The State of Florida possesses a wealth of talent that can be successfully applied to these problem areas. The RD&D Division maintains liaison with both the universities and public and private businesses within the state. A limited amount of funding is available to the division for direct support of research projects by these organizations. For more substantial efforts, organizations are encouraged to apply to federal and other funding sources for the needed resources, and assistance in this process is provided by the Center where appropriate. For projects involving institutions, the Florida Solar Energy Center may act as a coordinator for the project or may furnish overall project direction.

Probably the strongest stimulus that can be given to the development and application of solar energy equipment is provided by highly visible demonstra-

tions. They not only give the consumer an opportunity to see practical devices in operation, but also provide the manufacturer a showplace for his product. Only through such demonstration projects can the designers and installers gain the kinds of experience and feedback they need to provide reliable and marketable systems.

In Florida, the best candidate for immediate widespread application is the solar water heater. These have been in use throughout the state since the 1920's, but with the increased cost of conventional fuels there is a renewed interest, and with it a significant increase in the number and kinds of available equipment. A related and currently practical solar energy application is that of pool heating, but its potential impact is far less than that of water heating.

Demonstrations are planned in solar technologies that may be useful in the state of Florida, but demonstrations beyond that of water heating are developmental in nature and are research-oriented. A developmental system with great potential for intermediate-term impact on energy in Florida is solar air conditioning. Although there is no long-term experience with large solar-operated air conditioning systems, organizations throughout the state have expressed interest in such projects. This interest comes from school boards, community colleges, state universities, and hospitals. Hopefully, in the next few years many of these projects will be implemented and will demonstrate the feasibility of large solar cooling systems.

Residential use of solar cooling offers a special set of engineering challenges. Many of the techniques that might be employed in a large facility would require more supervision during operation and greater attention to maintenance than the homeowner normally can afford. Solar cooling of homes probably will depend on the prior development of reliable systems for large buildings. Research and development of solar air conditioning are proceeding well in Florida, and the division is in close contact with these efforts.

Many uses of energy require generation of electricity. Solar electric power generation can take many forms, including:

- Photovoltaic conversion.
- Rankine engines to drive electric generators.
- Ocean thermal energy.
- Wind energy.
- Energy in selected biological materials.

Utilization of solar energy for the production of electric power presents challenges both economically and technically. In these technologies the RD&D Division will help to coordinate research efforts in the state and obtain federal funding for research and demonstration. The combined efforts of industry and university researchers will be encouraged to bring broader experience to these problems.

To provide the purchaser with some assurance in the performance of solar equipment, the Center will independently test and verify performance data claimed by manufacturers and vendors. The testing may be done at the Center, or the results of tests performed at independent laboratories may be accepted by the Center. An effective test and standards program benefits the purchaser,

and it can provide a needed service to the small manufacturer who lacks expensive test facilities. The RD&D Division currently is assembling its test facility.

Features of the test facility include:

Compatibility with other test facilities and standards, including these of the National Bureau of Standards.

A testbed for measuring performance of flat-plate collectors, with all appropriate monitoring devices.

Instrumentation for measuring direct and diffuse components of solar radiation and associated meteorology.

A data processing unit for storing, retrieving, evaluating, and presenting data, such as collector efficiency, absorbance, and emissivity, as well as statistical parameters such as expected value, variance, and prediction. The data processing system also will facilitate engineering design and energy load determination.

THE ENERGY SYSTEMS ANALYSIS DIVISION—The Energy Systems Analysis Division has responsibilities in four principal areas:

Technology assessment and economic analysis.

Policy alternatives and implementation.

Project planning and analysis.

Energy conservation.

The Division performs technical assessments for the Center on the status of technology and activities in areas within the federal solar energy effort, particularly as these may apply to Florida. Examination of the technology in these areas will aid in establishing a position for the Center with respect to solar alternatives and will identify promising areas for FSEC activity.

An economic analysis of near-term solar energy systems for hot water and space heating and cooling is being carried out to determine the influence of initial system costs, fuel costs, and the cost of money on the payback periods for specified kinds of applications. The Division is identifying barriers to the implementation of existing solar energy technology and the means for reducing such barriers. Policy alternatives which may be available at both the state and local levels are considered. The Division, on request, advises the Florida Legislature on solar energy, and when appropriate, helps to prepare legislation. The Center interacts closely with other states and with federal agencies and maintains a cognizance of similar activities at the state and federal levels.

The Division is working with state and local governments and with the solar energy industry to examine proposals for the establishment of voluntary standards for solar energy equipment, and to examine efforts to use sales tax and other incentives to further the applications of solar energy. The division is preparing and will publish an inventory of the solar energy industry within the state. This inventory will help to identify the manufacturers and their solar equipment, as well as the distributors, and installers. An effort to evaluate the level of technical sophistication within the industry is in progress.

The allocation of resources of the Center and establishment of priority programs and projects for the Center are included within a project planning and analysis function within the division. Investigations are carried out to identify those programs which appear most promising for the Center and are best matched to the Center's resources, both over the near and the long term. The

Division, in coordination with agencies of the state and local governments, institutions, industry, and others, identifies and promulgates those conservation programs and practices which integrate with the application of solar energy. Initial efforts concentrate on conservation practices which can be instituted in the heating and cooling of residential, commercial, and industrial buildings, to facilitate the application of near-term solar energy equipment.

SPECIFIC EXAMPLES OF FSEC ACTIVITIES—Many actions are being taken at the Center consistent with the role in solar energy research and commercialization assigned by the State Legislature. As noted previously, the Center is assembling a sophisticated testing facility for solar systems. Initial testing, scheduled for operation in the late spring of 1976, will be for flat-plate collectors. Besides supporting research at the Center, testing services will be made available (on a cost reimbursable basis) to the solar industries in the state. At the outset, solar component analysis will aim at furnishing performance data. Certification of components will await clarification of this function.

A survey of the solar energy industry in Florida is underway. A strong viable industry is necessary if we are to see an increased use of solar energy systems. This survey is being done in cooperation with the Florida Department of Commerce. The information assembled will serve three purposes:

- It will provide a base line from which future progress in the commercialization of solar energy in Florida may be judged.

- It will allow evaluation and planning of the Center's activities in terms of established objectives and industry status.

- It will provide information from which a directory of solar equipment manufactured or sold in Florida can be compiled.

Analysis and development of legislation is another activity at the Center. Numerous bills relating to solar energy have been prefiled for Florida's 1976 legislative session. Because of the potential impacts of such legislation upon the advancement of solar energy in Florida, the Center is carefully reviewing and monitoring each bill. The Center has provided extensive work for two bills in response to legislative request. One bill would require that the Center establish a quality assurance program for solar equipment; the other would provide a sales tax exemption for purchasers of certain solar equipment.

The Center is engaged in discussions with the Federal Energy Administration which would result in federal support in developing and defining a state program for solar energy utilization and a role for utility companies in solar energy development. The effort would seek to identify steps required for a state program using federal and local government cooperation as a part of a comprehensive commercialization program.

To increase Florida participation in the national solar energy demonstration program, the Center has initiated two other activities. One involves assisting Florida firms in having their equipment classified as technically acceptable by U. S. Energy Research and Development Administration (ERDA), so that such equipment may be used in the ERDA and Housing and Urban Development (HUD) demonstration programs. The other consists of reviewing proposed demonstration project proposals submitted by Florida firms to ERDA with a view towards rendering assistance.

THE NATIONAL SOLAR ENERGY RESEARCH INSTITUTE—The 93rd Congress in 1974 (Public Law 93-473) directed ERDA to establish a national Solar Energy Research Institute (SERI). The potential economic impact of such a large operation on the local community where SERI will be located is considered highly beneficial and, hence, has aroused intense efforts by states, organizations, and regional consortiums seeking designation of their area as the SERI site. Florida has a task force, appointed by the governor, preparing a proposal for attracting the SERI program to the Cape Canaveral area. Because of a similarity of missions of the Solar Energy Center and the Florida task force seeking SERI, and because both are located at the Solar Energy Center, the two programs often are confused as being the same. They are not! The Center is supporting the SERI proposal effort in Florida, but the two programs are separately staffed.

Florida will offer many incentives in its proposal for the SERI site, and conversely the SERI project would be of great benefit to Florida. Near proximity of the Center to the proposed SERI site (they are not the same site) clearly would be advantageous to furthering the RD&D programs of the Center. Thus, the Center supports and encourages a cooperative state-wide effort in preparing a strong, technically sound, SERI proposal. With the release of the SERI guidelines by ERDA on March 15, 1976, the Florida proposal will be submitted by the July 15, 1976, deadline.

FUTURE FSEC ACTIVITIES—Exciting possibilities exist for large-scale solar energy utilization. One example is the solar power tower concept, which involves the use of a large field of tracking mirrors to focus the collected sunlight onto a receiver at the top of a central tower. The solar energy is converted to high-temperature heat which is used to generate electricity by means of a steam or gas turbine driving an electric generator. Another concept especially appropriate to Florida is the utilization of ocean thermal gradients to drive a Rankine engine.

ERDA is committed to research both concepts and has sizeable development programs in each area. The Florida Solar Energy Center is attempting to develop the capability within Florida for making major contributions to both programs. In the somewhat more distant future are additional concepts, such as the Boeing-proposed Powersat, an earth-orbiting synchronous satellite with a very large solar-collecting capacity. With Powersat, the collected sunlight is converted into a beam of microwave radiation which is sent down to a receiving antenna on earth for conversion into electricity. The Center will closely monitor development of this concept since it has special implications for Florida.

Photovoltaic conversion of sunlight into electricity is an approach with many potential advantages, including absence of moving parts, a capability for collecting diffuse as well as direct sunlight, and absence of a need for working fluids or complicated mechanical structures. A photovoltaic system could be adapted easily for use by electric utility companies with little need for personnel retraining. Substantial improvements in photocell efficiency and reduction of manufacturing costs will be required before photovoltaic systems will be economically viable.

Since no system has yet been devised for practical storage of electrical energy for later use, and since there is a great need for other forms of portable stored energy, there always will be a corresponding need for stored chemical energy, in the gaseous, liquid, or solid state. Hydrogen is an attractive gaseous fuel. It burns cleanly, is abundant, and can be readily stored and transported. The staff of the Center is searching for efficient and relatively inexpensive systems which produce hydrogen from solar energy. Existing techniques are neither efficient nor inexpensive. Thus, further research and development work is needed.

As the costs of fossil and nuclear fuels increase, there will be increased interest in the development of new forms of solar energy conversion. Active and creative minds will devise additional new approaches to the use of solar energy for human activities. As the science and technology of solar energy utilization develops and matures, the Florida Solar Energy Center will seek to provide leadership in this development and will search for ways of making this new technology readily available to the people of Florida. The Center welcomes cooperative involvement with educational institutions and industries throughout the southeast in this endeavor.

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Academy Symposium

SOLAR RESEARCH AT THE UNIVERSITY OF FLORIDA SOLAR ENERGY AND ENERGY CONVERSION LABORATORY

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ABSTRACT: *Over the past 20 yr, the University of Florida Solar Laboratory has contributed to knowledge now utilized in solar energy applications. The Laboratories now are investigating many principles established in the past in light of state-of-the-art materials and techniques. Research areas include: space heating and cooling with solar energy, refrigeration, solar distillation, solar to electric power conversion and solar cooking—to name a few. Work already done is reviewed as well as an overview of present research endeavors and future activities such as the United Nations project for establishing world-wide energy centers.*

ALTHOUGH the beginnings of solar research at the University of Florida date back as early as 1936, the University of Florida Solar Energy and Energy Conversion Laboratory did not reach maturity until some 20 yr ago when Dr. E. A. Farber joined the University staff. Since then the Laboratory's record of accomplishments in the field of solar utilization has earned international as well as national attention. A broad spectrum of solar research, encompassing projects from aerospace to residential needs, has focused at the University of Florida Solar Laboratory. More recently, with the increasing energy cost affecting every individual, the Laboratory has concentrated much of its effort on residential advances, applying many principles investigated in earlier research endeavors with up-dated materials. Parallel with these activities, however, new vistas of an inter-

national flavor have appeared as the University of Florida has been selected to participate with the United Nations in establishing several world-wide rural energy centers.

DOMESTIC WATER HEATING AND SOLAR SPACE HEATING—Several years ago the Solar Laboratories implemented a solarization project to retrofit the Mechanical Engineering Research Residence (a single family unit containing 1400 sq ft of living space) with solar equipment. The first phase of the program had as its objectives the conversion of the gas fired domestic hot water supply to a solar powered unit and the installation of a solar space heating system.

A solar water heater, which had been donated to the University of Florida some time before was installed on the carport roof and connected to the supply of the existing gas fired unit (Fig. 1). This arrangement afforded two advantages:

- 1) The thermosyphon effect created by the tank-collector orientation shown in the Figure eliminates the need for a pump or a controller.
- 2) By connecting such a unit to an existing hot water heater allows continued use of the existing unit as an auxiliary heater and storage unit.

Two disadvantages of such a system focus around:

- 1) The problems associated with freeze protection and
- 2) The necessity of having a collector constructed of materials compatible with city codes and able to withstand city water pressure and scale buildup.

More recent developments in solar water heaters utilize the dual system concept where a vessel containing the potable water is jacketed with a heat exchanger which in turn is connected to a solar collector. The fluid contained in the jacket may be treated with corrosion inhibitors and antifreeze (as codes allow) which affords greater flexibility in selecting materials for the collector core.

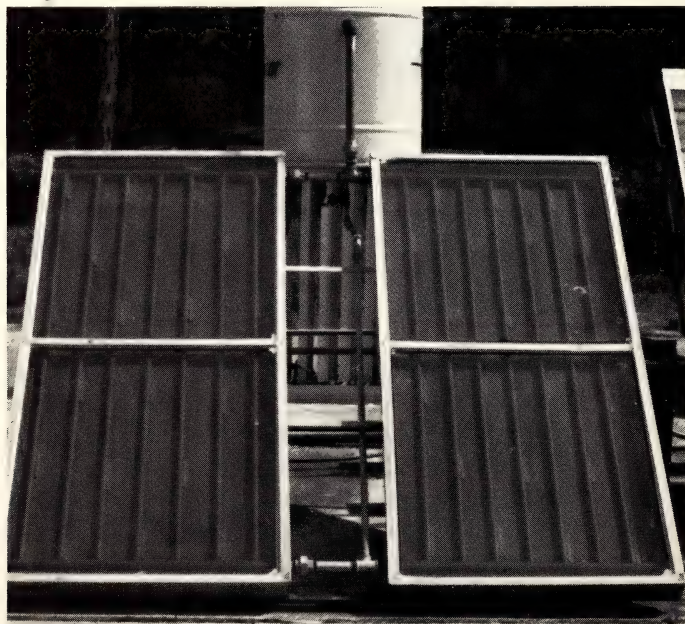


Fig. 1 Solar hot water heater.

Concurrent with the installation of the solar water heater, the solar space heating system was being constructed. This first project utilized a bank of ten flat plate collectors (36 sq ft each) connected to a 3,000 gallon insulated steel storage tank. The tank was situated on concrete stirrups slightly above the level of the collectors so the thermosyphon effect could be used for circulating the heat transfer fluid (a mixture of antifreeze and water). A small (1/6 hp) pump, controlled by a conventional thermostat located in the house, circulated water through baseboard convectors located along the inside perimeter of the living space.

This system was evaluated for several heating seasons and found to be quite satisfactory. It offered two advantages:

- 1) low electric power consumption as only a single pump was required to circulate the heat transfer fluid and
- 2) the baseboard convectors provided a quiet, even heat throughout the living space.

It also had its disadvantages:

- 1) The system required antifreeze for freeze protection. At the conception of this system, this was economically feasible for a 3,000 gallon tank, but at today's prices it would be difficult to justify such a freeze control procedure.
- 2) Most Florida homes are slab-on-grade construction so that the retrofit installation of baseboard convectors would be very costly.
- 3) Orienting the tank and collectors as done for this project could also create esthetic problems for the typical homeowner.

The second generation system now located at the University of Florida Solar Research Residence (Fig. 2) has the solar collector bank located on the roof. In the new design, extra collector area was added to provide sufficient capacity for the operation of the solar air conditioning system. A centrifugal pump (1/4 hp) controlled by a differential temperature controller circulates fluid from the tank through the collector bank (12 collectors at 48 sq ft each). When the temperature of the water in the collector bank exceeds the temperature of the water at the bottom of the tank near the inlet to the pump, the differential controller is energized and fluid is circulated through the collector bank. If this condition reverses for any reason, e.g. the sun goes behind a bank of clouds for some period of time or the sun sets in the evening, the differential temperature controller de-energizes the pump and stops the circulation of fluid through the collector bank. Freeze protection is provided by a separate sensor located in the collector bank. If the temperature of the collector bank drops to within a few degrees of freezing, the differential temperature controller energizes the pump long enough to fill the collector bank with some of the hot water contained in the storage tank.

The new heating system has also been evaluated for several heating seasons. Two modes of introducing heat into the living space have also been investigated: a baseboard convectors system and a forced air system. Data taken during the test period indicate that both systems can adequately provide a comfortable environment for the residents of such a solar powered home (Farber et al., 1975). A full report on this study is expected in thesis form about June, 1976.

SOLAR SPACE COOLING—Although the University of Florida Solar Labora-



Fig. 2 Front view of solar house.

tories have constructed eleven solar power refrigeration units over the last 20 yr, all have been experimental prototypes constructed mainly to investigate the capability for producing a refrigeration effect with solar energy. Some of these units used fluids heated with solar concentrating devices and some used fluids heated with conventional flat plate collectors. To meet today's needs and to add another dimension to the University of Florida's solarization project, the Solar Laboratory designed and constructed a 2½ ton solar air conditioning unit to provide comfort cooling for the Solar Research Residence. The system selected was an ammonia/water absorption unit. Earlier investigations indicated that this system provided the greatest flexibility for operation with solar heated fluids.

The unit installed at the Solar Research Residence (Fig. 3) is classified as an intermittent ammonia/water absorption unit; it is so called because of the intermittent way in which refrigerant is generated and expended by the system. Hot water is circulated from the insulated storage tank through a heat exchanger located in a vessel designated as the generator/absorber which contains a solution comprised of ammonia and water. As heat is liberated from this solar heated water to the solution, ammonia vapor is driven from this vessel to an adjacent vessel designated as the condenser/evaporator.

Cooling water furnished by a cooling tower is circulated through a heat exchanger located near the top of this vessel. The ammonia vapor is condensed to a liquid form and collects in the bottom of the condenser/evaporator vessel. This mode of operation is referred to as the generation mode and is designed to take place in a very short period of time. During this part of the operation chilled water may not be furnished to the house. When a sufficient level of refrigerant has been produced, the air conditioning unit is then available for cooling the house.

The cooling water is diverted from the condenser section of the condenser/evaporator to the tube bank located in the bottom of the generator/absorber, thereby dropping the temperature and pressure of the solution contained in that vessel. The reduced pressure in the system allows the liquid ammonia contained in the condenser/evaporator to vaporize at a low temperature. Water circulated through a heat exchanger located in the bottom of the condenser/evaporator vessel liberates its heat to the liquid ammonia thereby vaporizing the ammonia and cooling the water.

The chilled water is circulated through a coil located in the forced air cooling system of the house. As the ammonia vapor leaves the condenser/evaporator it returns to the generator/absorber which is now functioning as an absorber and is re-absorbed back into solution. When the initial charge of ammonia refrigerant has been expended from the condenser/evaporator, the control returns the air conditioning system to the generation/condensation mode and a new charge of refrigerant is generated (Farber et al., 1975).

The intermittent ammonia/water absorption air conditioning system has been evaluated for approximately two cooling seasons. The system is currently being instrumented with automatic controls to evaluate new control techniques which were developed during the initial experimental work performed on the unit. Work is underway on the design and construction of a continuous ammonia/water absorption air conditioning system which will be installed at the University of Florida Solar Research Residence. This work is a follow-up to a study recently completed by J. A. Clark (1976) which is available in thesis form.



Fig. 3 Solar air conditioner.

SOLAR DISTILLATION—Another facet of the increasing cost of energy which has probably eluded many of us, but has become a serious problem for many others has been the energy required to produce potable water from either waste water or saline water. The University of Florida has recently completed a study with the city of St. Petersburg in which solar energy provided a viable solution to a growing need for fresh water by the city.

In a more scientific vein, the University of Florida Solar Laboratories are investigating solar distillation on two levels of research. In one case a system is being designed for residential use so that some of the waste water normally produced by a household can be economically distilled with solar energy and used for some other purpose. The design under construction incorporates some fairly unique concepts and should provide an interesting result when the project is completed. A second project is investigating the thermal properties of the fluids involved in solar stills in the hopes that some increase in the still's efficiency may be achieved by affecting such things as surface tension of the fluid and the mobility of the vapor molecules leaving the surface of this liquid.

SOLAR TO ELECTRIC CONVERSIONS—There is a multi-prong effort at the University to investigate methods of converting solar energy to electrical energy. Several of these efforts are being made by men such as R. L. Bailey (1975) of the Department of Electrical Engineering. Dr. Bailey's efforts have been in the direct conversion of solar energy to electrical energy.

The Solar Laboratories have recently completed a study of a system which could be utilized at the residential level for converting solar energy to a thermal process to electrical energy. As an example, flat plate collectors would be used to heat water which would be stored in an insulated tank. Hot water in this tank would be circulated to a boiler where some motive fluid would be produced and in turn would drive some device such as a turbine connected to a generator. The electric generator would furnish power to a bank of batteries for electrical storage or could furnish electricity directly to the home to supplement electrical energy received through normal utility connections. The results of this study is expected to be available after June of 1976 in the form of a thesis by Paul Arnold entitled, "The Production of Electric Power with a Rankine Cycle Utilizing Solar Energy".

COOKING WITH SOLAR ENERGY—Two years ago the University of Florida Solar Laboratories embarked on a rather unusual project; the investigation of a system for providing 24-hr cooking capability for a typical residence. In the process of analyzing the various components which would make up such a system, several innovative ideas were realized which could be used in many other solar applications.

The basic cooking system, as originally conceived, would be comprised of an insulated storage tank equipped with a submersible pump, containing a high temperature heat transfer media, and a cooking range located in the house. The utilization of high temperature heat transfer media would then provide the various cooking functions.

Each of these components in itself provided a special design problem. The

insulated storage tank with submersible pump must be large enough to provide enough capacity to provide at least a day or two days cooking capability, it must be constructed in such a way to meet fire codes, and it must be equipped with a pump which will provide reliable performance in the temperature range of 400-600°F which are being considered for the project. Phase change materials are also being considered for this storage capability.

The heating elements must perform as well as conventional heating elements. They must be able to respond quickly to changes in the flow rate of the heat transfer media (Elder, 1975). The operation of the oven section of the range should be quite satisfactory, as all the surfaces of the oven may be used as radiating surfaces if the walls are constructed as heat exchanger panels through which the heat transfer media may be circulated.

A concentrating collector to be used with the system did not present any new problems, as several of these units have been built and tested at the University of Florida Solar Laboratories. However, it proved desirable to have a tracking mechanism which would be essentially maintenance free if such a collection system were to be utilized at the residential level. The ultimate solution of this problem was found in the design of a fluid-mechanical system deriving its power for operation from the sun; making it completely independent of any electrical power input. The tracking device utilizes two sensor bulbs containing a low boiling point fluid which are located on the parabolic collector. If these sensors are shaded unequally pressure differentials created in the sensors drive power cylinders, which in turn, through a rack and pinion drive system rotate the large parabolic collector in alignment with the sun. The device also offers an advantage in that if the sun should go behind some clouds for several minutes the unit will reset itself as soon as the sun clears the clouds. Of course, the device will also drive the solar concentrator back to an eastern orientation in the morning when the sun rises. An evaluation of the tracking device indicates that it has a very good response time and tracks the sun within a few degrees (Morrison et al., 1976).

SUMMARY—In summary, the University of Florida has been involved on many fronts of solar research and development, too many to discuss in a single paper. Other projects within recent years have involved such things as selective coatings for flat plate collectors, evaluation of heat transfer coefficients for the ammonia/water system, studies of solar powered refrigeration units, solar calorimetry, just to name a few.

New fronts which are opening up for research in the area of solar energy, even though possibly on a lower technological level, may have world-wide impact for those newly developing nations. The United Nations has within the last year implemented a program where the University of Florida and two other research groups will participate jointly in the research and development necessary for the construction of rural energy centers in areas of the world requiring very basic needs such as fresh water, light, and cooking capabilities.

LITERATURE CITED

- BAILEY, R. L. 1975. Electromagnetic Wave Energy Conversion Research. Grant No. NSG-5061, NASA Rept. Sept. 30, 1975.

- CLARK, J. A. 1976. An Investigation of a Solar Powered Continuous Ammonia/Water Absorption Air Conditioner for Residential Buildings. M. S. thesis. Univ. Florida. Gainesville.
- ELDER, K. M. 1975. A Solar System with 24-Hour Food Preparation Capability. M. S. thesis. Univ. Florida. Gainesville.
- FARBER, E. A., C. A. MORRISON AND H. A. INGLEY. 1976. Using the sun to heat, cool and cook at the University of Florida Solar Research Residence. Building Systems Design 75 (1):
- _____, _____, _____ AND E. SUAREZ. 1975. The University of Florida solar powered intermittent ammonia/water absorption air conditioner. Proc. 21st Ann. Tech. Mtg. Instit. Environ. Sci. 1:202.
- _____, _____, _____ AND F. J. TARUD. 1975. Heating buildings with solar energy. Proc. 21st Ann. Tech. Mtg. Instit. Environ. Sci. 1:190.
- MORRISON, C. A., E. A. FARBER, H. A. INGLEY AND D. B. WIGGINS. 1976. Solar powered tracking device. Building Systems Design 75(1):

Florida Sci. 39(3):181-188. 1976.

Academy Symposium

SOLAR ENERGY RESEARCH AT THE GEORGIA INSTITUTE OF TECHNOLOGY

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ABSTRACT: *The Georgia Institute of Technology is currently engaged in a wide range of solar energy research projects funded by ERDA, NSF, NASA, USDA, and other agencies. A major agricultural applications project is developing several types of low-cost, but effective, solar collectors for farming use. A complete home heating and cooling system is being installed on the campus; one large solar heated and cooled building is completed and another is under construction. A new type of fixed mirror concentrator, which has been operating since last summer, is undergoing continuing testing and improvement. The largest research effort at Georgia Tech is directed toward central station power generation; projects include the installation of 400 KW solar steam plant on campus, development and testing of a 5 MW thermal storage unit, and design of the United States solar thermal test facility. Extensive involvement in international programs has also been a highlight of Georgia Tech's solar energy efforts. Cooperative efforts are underway or proposed with ten other countries including France, Italy, Algeria and Canada.*

THE Georgia Institute of Technology has one of the largest and most varied solar energy research and development programs at any university in the United States. Sponsored programs on the utilization of solar thermal energy cover the entire temperature range from agricultural drying, which may require a temperature of only 10° above ambient, to central station power plants using a large array of mirrors to focus intense sunlight onto a boiler.

AGRICULTURAL APPLICATIONS—In agriculture, there are substantive energy requirements, particularly for drying. A variety of crops such as corn, soybeans, peanuts, tobacco, grapes, fruits, pecans, and forage may be dried prior to conversion to commercially viable products. While many crops have been field-dried for centuries, this process leaves the farmers' profits at the mercy of the elements of nature which range from destruction by rodents and mold to destruction by simply poor weather. Estimates from USDA 1973 harvest statistics indicate that Georgia peanut crops consume on the order of 10^{11} BTU in drying

energy annually. Similar demands occur from other crops. All of these crops, except forage, are dried at low temperature, making solar energy an extremely attractive alternative to bottled gas, which now retails in many locales at more than \$3/million BTU. Flue-cured tobacco is one of the most interesting crops from a design standpoint in that five different temperature plateaus from 90°F to 170°F are used over a typical drying time in excess of 100 hr.

At Georgia Tech, a comprehensive program in improvement of agricultural drying collector design and associated instrumentation has been undertaken. This program is under the sponsorship of USDA and the Georgia Institute of Genetics. J. H. Schlag and A. P. Sheppard are co-principal investigators on the project with active participation from D. C. Ray and J. M. Wood. Extensive comparisons have been made on the physical properties of various collector glazing materials—glass, fiberglass reinforced plastic, various polyethylenes, PVC and PVF. Life cycle, transmittance, relative cost and ease of use have all been considered. The relative advantages and disadvantages of water and rocks as storage media have been examined. Collector designs being studied include:

1. A rock heat collector, which consists of a 6"-18" layer of black painted rocks under two layers of glazing separated by an air gap. During the day when more heat is being produced than is being used, air can be recycled to heat the entire layer of rocks. Thus, the rock bed serves both as a solar collector and an energy storage system.
2. An air heating collector, which consists of a single layer of clear glazing, a stagnant air gap, and a layer of black polyethylene. Air can be pulled behind the layer of black polyethylene. Storage is obtained by circulating the hot air through a rock bed.
3. A solar pond which consists of a layer of glazing material, a stagnant air gap, and a layer of glazing floating on 6" of water which rests on a black polyethylene backing.
4. A solar greenhouse, of modular construction, which consists of two layers of plastic glazing on the south facing wall and a reflective north wall. Heat storage for night operation is provided by rocks stored beneath the structure.

Comparative performance data of the various collectors are being obtained.

Emphasis has been placed on the instrumentation and data acquisition system used to collect performance data. A microprocessor and digital recording system form the nucleus of this system. A time multiplex scanner has been developed which can handle as many as sixty thermocouples monitoring various collector system points. The following measurements are now being routinely obtained.

1. Temperature—using self-compensating thermocouple systems and thermistors.
2. Humidity—using optical dew point and wet bulb-dry bulb.
3. Flow Rates—using turbine flow meters for water and hot wire anemometers for air.
4. Insolation—pyranometers and pyrheliometers for measuring total horizontal insolation, total incident insolation, direct incident insolation, and the spectral distribution of the insolation.
5. Wind speed using a cup-anemometer.
6. Wind direction using a weather vane.

The primary applications of these systems are intended for crops of peanuts, tobacco, and forage—important to the southeastern United States, although they

should be readily extended to other crops which are hung or layered in small barns or trailer-type vehicles.

HEATING AND COOLING FOR HOMES—A complete solar home heating and cooling system using 44 modular collectors of different types is being installed, under the direction of the authors, on a platform on one of the Georgia Tech Mechanical Engineering buildings. Hot water from the collector array is used to operate an Arkla-Servel 500 WF 3-ton absorption air conditioning unit to cool two classrooms that were not previously air conditioned. Two 2000 gallon steel tanks are used for hot water storage. This project serves two purposes:

1. It provides students, faculty, interested professors, and the public an opportunity to see a complete, operating home solar heating and cooling system, with all major components exposed for inspection. Modifications of the system configuration and control logic can be easily made to permit testing and evaluations of a wide variety of different types of solar home heating and cooling systems.
2. Since each of the eight different types of solar collectors in the array are separately instrumented, the long-term average efficiency of each type of collector can be measured while the collectors are actually being used to provide cooling or heating in Atlanta. Thus, this versatile system will also be used as a test bed for solar collectors and other solar system components.

At the present time, all 48 collectors (900 sq ft) are on the building, and the chiller storage tanks and other major components are at Georgia Tech. The solar and wind data station on the same building has been monitoring total and direct-only insolation and wind speed and direction for the past eight months. The data acquisition system which is being installed will record these data and all pertinent system performance data on computer-compatible tape for analysis.

HEATING AND COOLING OF BUILDINGS—The first major building project involving solar heating and cooling, in which Georgia Tech participated, was the George A. Towns Elementary School of the Atlanta, Georgia, City School System. This project was undertaken in 1974-75 with Westinghouse Special Systems as prime contractor, Burt-Hill and Associates as the solar architects, and Georgia Tech as monitoring and instrumentation project engineers. Dr. S. C. Bailey served as principal investigator on the Georgia Tech portion of the project, and was aided by Professors F. Clarke, J. Craig, and P. Kadaba.

The Towns School is an existing one-story, 32,000 sq ft elementary school building serving about 500 students. It was already equipped for hot water heat and chilled water air conditioning although no chiller had ever been installed. Pittsburgh Plate Glass Industries solar panels were mounted on the roof at a slope of 45°. There were 10,000 sq ft of flat plate collector installed. A total of 576 collectors were used. In addition, a crude collector reflector of aluminized Mylar[®] sloping downward toward the north at 36° was mounted to provide additional radiation to the collectors during the summer months. There were more than 12,000 sq ft of this crude reflector used. The design was such that there would be a maximum gain factor of about 1.7 during the month of August which would furnish a total radiant power of about 400 BTU/sq ft.

The storage system for the building consists of three 15,000 gallon water tanks. All three tanks are designed to hold 140°F water in mid-winter, whereas

in summer, two of the tanks will run at about 200°F water and the third tank is storage for chilled water. The 100 ton Arkla lithium bromide absorption chiller is used for the cooling. While the system only went into operation in late November 1975, it is expected on a year-round basis that about 60% of the cooling and heating will be obtained from solar energy.

Dr. J. Richard Williams is responsible for the construction of a new 54,000 sq ft multipurpose community center incorporating 10,500 sq ft of flat plate solar collectors in the roof, with augmentation by 14,000 sq ft of polished aluminum reflectors which provide additional heat input during the summertime as shown in the model photograph of Fig. 1. Thermal storage is provided by a 15,000 gallon, 400 psig, hot water storage tank and two 30,000 gallon unpressurized steel tanks for chilled water storage. In addition, a 4,000 gallon hot water storage tank in the primary flow loop prevents excessive cycling of the 100 ton LiBr absorption chiller. The building is partially underground and incorporates numerous energy conserving features. The individual 21×8 ft solar collector modules are factory-assembled for low-cost installation on the building. They are rated for 500°F dead-end temperature, use selectively coated copper absorber plates, are double glazed with low-iron glass, insulated to R-20, and warranted for a full year by the manufacturer. The solar energy system will provide over 90% of the total annual energy required for winter heating and at least 50% of the total annual energy required for summer cooling. In addition, it will supply hot water

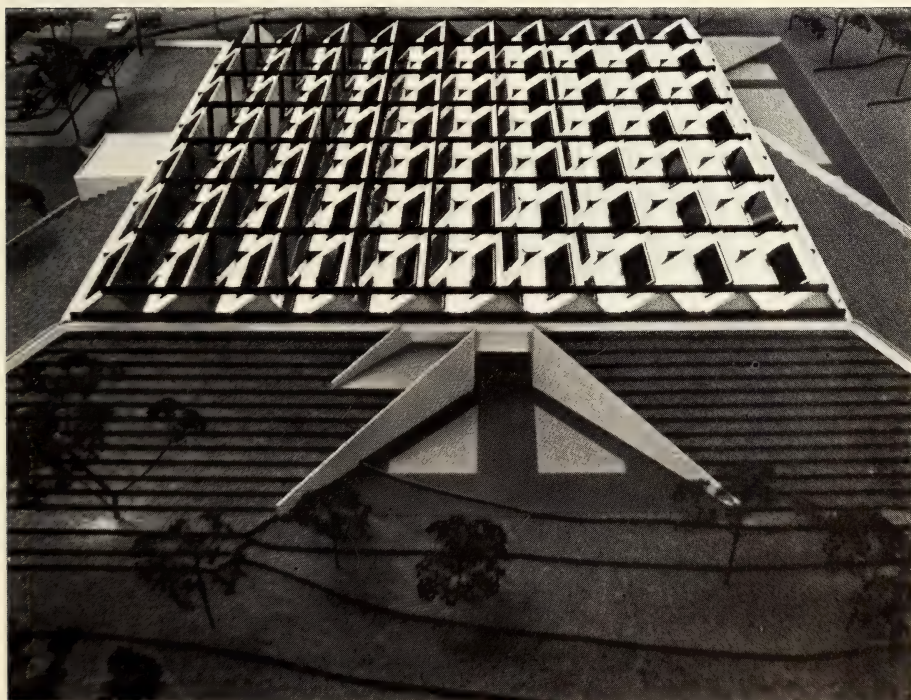


Fig. 1. Model of Shenandoah Community Center.

for domestic use and for servicing the ice rink. In the autumn and spring, heat from the solar collectors which is not needed for space heating, cooling, or hot water, will be used to heat an adjacent swimming pool. This project is being supported by a \$730,000 grant from ERDA, and is expected to be completed in September of this year.

LINEAR FOCUSING COLLECTORS—Some important solar energy applications require higher temperature collection than is practical with flat plate collectors, so focusing collectors must be used. Since large concentrating surfaces are subject to high wind loadings, it is often advantageous to fix the reflecting surface in a stationary supporting structure and steer a much smaller heat exchanger so that it remains in the focal region. Several fixed concentrator moving heat exchanger systems have been proposed using spherical and parabolic concentrators. The faceted fixed mirror concentrator (FFMC) has no off-axis aberration and focuses sunlight sharply regardless of the incident light direction. It is composed of long, narrow flat reflecting elements arranged on a concave cylindrical surface, and the heat exchanger is supported on arms that pivot at the center of the reference cylinder. Concentrators of this general type are useful for applications such as supplying air conditioning, process heat, and electrical power.

A 540 sq ft prototype FFMC has been built at Georgia Tech (Fig. 2) under the direction of Dr. Williams with a \$280,000 grant from NSF and ERDA. The reflector array is 7 ft wide and 80 ft long with 28 single-weight 2.9 in wide rear-surfaced mirror slats symmetrically positioned about the concentrator axis. The subtended angle of the cylindrical surface on which the slats are positioned is 105° , and the collector is oriented east-west and tilted at the latitude angle. The heat exchanger for heating air is constructed with a terminal concentrator consisting of polished aluminum and stainless steel reflectors to minimize heat loss and maximize heat absorption on the side facing the reflector. Heat collection temperatures in excess of 800°F have been measured. An automatic steering device maintains the heat collector at the focus and rotates it so that the receiver aperture always faces the center of the concentrator. The reflecting mirrors are supported by aluminum extrusions which are supported by aluminum ribs. A tank of stones is used to store heat at about 500°F . The collector is located on the roof of one of the Mechanical Engineering buildings at Georgia Tech.

This collector was constructed only of components of proven durability and acceptably low cost. Thus, commercial rear-surfaced mirrors with a reflectivity of 85% and a cost of 35¢/sq ft were chosen for the reflecting facets. The ribs and supporting extrusions are of aluminum alloy, and the fasteners are of cadmium-plated steel. All metallic surfaces are coated to enhance the appearance of the concentrator and increase its durability.

This collector heats air to 600°F with an efficiency of about 40%. A new evacuated heat exchanger (receiver) with thermanol as the heat transfer fluid is now being installed, and should increase the collector efficiency to 60% at 600°F . This collector is now for sale at \$35/sq ft, and \$20/sq ft for more than 10,000 sq ft.

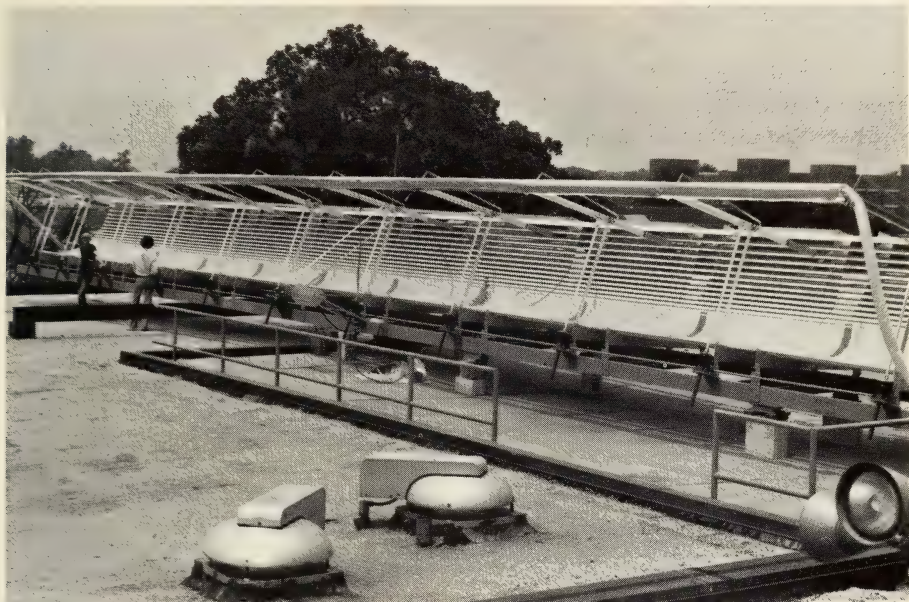


Fig. 2. Faceted Fixed Mirror Concentrator located atop the Mechanical Engineering Building at Georgia Tech.

SOLAR FURNACES—Georgia Tech has conducted materials research programs in collaboration with the Centre National de la Recherche Scientifique (CNRS) in France since 1972. CNRS owns and operates the 1000 KW Solar Furnace in southern France (Fig. 3) currently the world's largest high-temperature solar test facility. During its materials development activities, Georgia Tech identified a military need which called for measurement of the radar transmission properties of materials while those materials were subjected to high heat fluxes. Conventional heating methods, such as the use of flames or electrical radiant heaters, either interfered with the radar measurements or were incapable of reaching the desired heat fluxes. The CNRS Solar Furnace offered the possibility of attaining very high heat fluxes using pure radiant energy which did not interfere with radar. The first sponsored program was a fundamental study on the behavior of ceramics and metals subjected to pulses of intense thermal radiation. Many of the specimens reacted differently than expected, and the resulting experimental data were useful to the Army for radar design purposes and to NASA for designing heat shields to be used on planetary entry probes for Venus and Jupiter. The second sponsored program was an applied study intended to measure the radar transmission characteristics of radomes (nose cones) used on missiles during reentry into the earth's atmosphere. The solar furnace allowed reentry heating to be simulated while the radar tests were conducted.

Georgia Tech has assisted the U. S. Army Test and Evaluation Command in calibration of the White Sands Solar Furnace and advised the facility operators on techniques for solar furnace measurements. The U. S. Army Solar Furnace was built in 1958 by the Quartermaster Corps at Natick, Massachusetts. It even-

tually fell into disuse, and in 1973 was moved to the White Sands Missile Range in New Mexico. There, it was assembled by the Nuclear Weapons Effects Laboratory, primarily for testing of military material under conditions simulating exposure to nuclear weapons. By the time the White Sands Solar Furnace was ready to resume operation at its new location, Georgia Tech had conducted two test programs at the CNRS Solar Furnace in France. The U. S. Army contracted with Georgia Tech to perform a new calibration of the heat flux at the focal point of the solar furnace and to assist in implementing newly developed measurement technology such as determination of temperatures by optical methods. The program was completed in 1975.

SOLAR POWER GENERATION—One major new project, funded by ERDA, is for the development and evaluation of a 400 KWth solar steam generating plant and test facility, the largest in the United States. The objectives of this program are to transfer solar energy technology developed in Italy to the United States and to provide an important test facility in this country. For about 15 yr, Professor Giovanni Francia of the University of Genoa in Italy has been engaged in the development of solar powered steam generators. His current design has progressed through four generations of development, with various modifications incorporated into the receiver and heliostat field. The present Francia Solar Steam Generation Pilot Plant in Genoa produces 100 KWth of superheated steam at 600°C and 150 atmospheres (1100°F and 2200 psi) which is well within the range preferred for electrical power generation. The new steam plant to be erected on the Georgia Tech campus will be about three times as large as the Genoa facility, producing about 300 KWth of steam at the same output conditions. This steam plant will follow the same general design used in Genoa and will be supplied by ANSALDO, S.p.A., an Italian industrial organization; ANSALDO will also supply professional services to assist in plant start-up and training of United States personnel. Acquisition of the Francia facility in the United States and careful study of Professor Francia's techniques is expected to yield substantial benefits to this country's solar thermal conversion program by broadening our knowledge and experience in this field. The facility is expected to be in operation at Georgia Tech in late 1976.

Another program involves the design, construction, and testing of a solar steam generator in order to acquire design information and operating data based on real experience. This is one of the early projects in solar thermal conversion begun under the National Science Foundation in 1974. Martin Marietta and Georgia Tech have conducted the program as a team, with collaboration of the Centre National de la Recherche Scientifique (CNRS) in France. The Energy Research and Development Administration (ERDA) assumed responsibility for the program when that agency was organized in 1975. This program also utilizes the CNRS 1000 KW Solar Furnace in southern France that is shown in Fig. 3. The solar steam receiver design was chosen on the basis of two primary considerations: (1) it must model as closely as possible the design expected to be used in a commercial solar electric power generation plant, and (2) it must be scaled for solar testing in the CNRS Solar Furnace. The solar receiver is designed to



Fig. 3. French CNRS 1000 KW Solar Furnace located in Odeillo in the eastern Pyrenees.

convert water to superheated steam at conditions acceptable for operation of conventional steam turbo-generating machinery; the output steam conditions will be 950°F and 1250 psi. It, thus, performs the function of the boiler-superheated in a normal fuel-fired electrical generating plant. The receiver is built in the form of a pyramid-shaped box with high-pressure steel tubing lining the interior walls. The tubing is illuminated by the concentrated solar radiation supplied by the solar furnace and water circulation inside the tubing is converted to steam. Georgia Tech has made major contributions to the receiver design and has provided special hardware required for the test program.

Another program involves the preliminary design of a 10 MWe (megawatt-electrical) Pilot Plant for generation of electrical power using solar energy. Georgia Tech is teamed with the Martin Marietta Corporation (prime contractor), Foster-Wheeler Energy Corporation, and the Bechtel Corporation. The project is one of four multi-million dollar design programs begun by ERDA in the summer of 1975, whose goal is to demonstrate the technical and economic feasibility of generating electric power by solar thermal conversion. Upon completion of the four independent Pilot Plant preliminary designs, it is likely that the best features will be adopted and merged into one or two final designs, followed by construction of one or two operating Pilot Plants. A 10 MWe Pilot Plant will be a miniature commercial plant and will incorporate all the technical features needed to be compatible with the complex systems operated by the electric power generation industry in the United States. It will be integrated into a commercial power net to demonstrate that it can perform within the rules

and strategies used to control such nets. The Pilot Plant is divided into four subsystems: (1) the Collector Subsystem consisting of the heliostats (mirror assemblies) which collect solar radiation and focus it into the receiver, (2) the Receiver Subsystem consisting of the solar boiler elevated on a tower, (3) the Thermal Storage Subsystem which stores heat for generation of steam during cloudy periods and in the evening, and (4) an Electrical Power Generation Subsystem which includes the turbogenerator, heat rejection apparatus and water supply equipment. Research Experiments have been designated for the above areas, each of which will model one of the pilot-plant subsystems.

Georgia Tech is responsible for the Thermal Storage Subsystem within the Martin Marietta Pilot Plant team, and will design, build, and test the Thermal Storage Subsystem Research Experiment. The Thermal Storage Subsystem Research Experiment will consist of a 2 MWth thermal storage system (about one-twentieth the size of the Pilot Plant thermal storage system). The Research Experiments will furnish real operating experience which can be used to improve the Pilot Plant preliminary designs. The principle adopted for this thermal storage system involves storage of heat in liquids. Two storage media are used at different levels of temperature: (1) a molten inorganic salt mixture to store heat at 850°F, and (2) a hydrocarbon oil to store heat at 570°F. The storage temperatures are established by the steam conditions necessary to drive the turbogenerator when the turbine is running on stored energy; the Thermal Storage Subsystem will supply steam at 750°F and 600 psi to the turbine. In order to test the Thermal Storage Research Experiment, charging steam must be supplied at 950°F and 120 psi. The only places where this steam is readily available are electrical generating plants, and arrangements have been made to construct the Thermal Storage Subsystem Research Experiment at the Georgia Power Company's Plant Yates near Newnan, Georgia, about 40 miles southwest of Atlanta. The Research Experiment occupies an area of about one-third acre adjacent to one of Georgia Power's generating units.

A 5 MW Solar Thermal Test Facility (STTF) is to be built at the ERDA installation operated by Sandia Laboratories near Albuquerque, New Mexico. The purpose of the STTF is to test experimental designs of solar receivers, heliostats (mirror assemblies), thermal storage systems and other high-temperature solar equipment. It is scheduled for operation at the 1 MW power level in late 1976, and at the 5 MW power level in mid-1977. Equipment to be tested will be supported on a central tower and illuminated by a surrounding field of heliostats. The prime contractor for the STTF Conceptual Design was Black and Veatch, Consulting Engineers. Black and Veatch subcontracted with Honeywell, Incorporated, and Georgia Tech for technical assistance in their respective areas of expertise. Georgia Tech was selected because of broad base of experience acquired in its work at the U. S. Army White Sands Solar Furnace and the CNRS Solar Furnace in France. Georgia Tech has provided technical recommendations concerning facility layout, arrangement of working space, safety and operating procedures based on its previous solar testing experience. Also, Georgia Tech has performed a conceptual design for a 1 MW "Working Receiver" which will

be owned by the STTF and used for heliostat alignment and testing, and has designed methods for protecting the test tower against damage by focused radiation inadvertently directed onto the tower.

The objective of another program is to develop a conceptual design for a solar electrical generation system using air, rather than steam, as the working fluid. The work is sponsored by the Electric Power Research Institute (EPRI): Black and Veatch is the prime contractor and Georgia Tech is a subcontractor. Georgia Tech's area of responsibility is the application of ceramic materials technology to the design of an energy receiver employing ceramic structured parts. The ERDA-sponsored work in solar thermal conversion is based on the use of the Rankine thermodynamic cycle with steam as the working fluid. EPRI is sponsoring two programs to investigate solar thermal conversion using the Brayton thermodynamic cycle with gases as the working fluids; one of these is the Black and Veatch/Georgia Tech effort based on a gas turbine driven by heated air. In this system, the gas turbine, electrical generator, and heat receiver, are all mounted at the top of a tower and surrounded by a field of heliostats. The gas turbine operates in much the same manner as a jet aircraft engine, except that the engine's combustion chamber is replaced by a solar-heated receiver in which the temperature of the air is raised to the range of 2200°F. There are several technical advantages to this approach for electrical power generation: (1) no equipment is needed for cooling the working fluid because the used air can be exhausted directly to the atmosphere, (2) gas turbines are less expensive than steam turbines of the same capacity, and (3) higher cycle efficiencies are possible in the gas system than with the steam, thereby reducing the number of heliostats required for a given electrical output. There are also disadvantages: (1) attainment of high cycle efficiency requires that air be heated to very high temperatures and this in turn demands that the receiver be constructed of ceramic materials rather than metals, a much more difficult fabrication task, and (2) the pressure drop caused by flow of air through the receiver must be kept very low to avoid severe penalties in cycle efficiency. The gas-operated solar electrical power generation processes thus require more fundamental development than the steam processes, but offer possibilities for better efficiency when success is achieved.

Georgia Tech is also assisting EPRI in defining the scope of testing services which they would need to support their various solar energy programs, to define the facility and site requirements for performing these tests and to develop a conceptual design and cost analysis for the facility. The federal government has recently expanded its funding of solar research programs. The programs vary from simple water heaters to highly complex solar power generation systems. Although a number of thermal storage systems are being studied for use at night or during inclement weather, presently conceived systems do not show promise for extended periods of use. It has also been determined that the most economical solar powered system uses little or no storage in many instances. All this says that an alternative source of energy is needed. The most likely source of this alternate energy is electricity. Few of the government sponsored programs have

looked into the impact of solar energy on the electric utility industry. If there is a great move to solar energy without careful consideration of alternative or standby energy sources, adequate reserve generating capacity may not be available. The EPRI Solar Programs are designed to look into the impact of solar energy on the utilities and the best approach to insure adequate standby energy. The purpose of the program discussed here is to determine what type of Solar Materials and Components Test Facility (SMCTF) is needed to support these programs.

The solar power generation and solar furnace work is being conducted in the Solar Energy and Materials Technology Division of Georgia Tech's Engineering Experiment Station. Among the principals who have had extensive involvement in these programs are N. E. Poulos, J. D. Walton, S. H. Bomar, C. T. Brown, and J. M. Akridge.

INTERNATIONAL PROGRAMS—While cooperation has been noted already with the French and the Italians in the area of high temperature solar thermal power generation, cooperative efforts have been initiated or are under discussion with researchers in a number of other countries. For example, efforts have been proceeding for more than a year with the Brace Research Institute of McGill University in Canada. Mr. Tom Lawand, Director of the Brace Research Institute Field Operations, is the liaison contact there. Among the areas where data exchange is taking place are solar cookers, solar ponds, and agricultural dryers. Plans are underway with Brace Institute for cooperative design of solar powered pumping and irrigation facilities in Mexico, Senegal, and Sri Lanka under the general sponsorship of the United Nations.

A program has been initiated with the ONRS (Organisme National de la Recherche Scientifique) of the Algerian Government for the implementation of a comprehensive energy research program in Algeria. This will consist of nuclear and solar energy research. At present, the Algerians have a 50 kw parabolic furnace operating atop the mountain on which the city of Algiers is located. The Algerians plan to build another large furnace in the Sahara of southern Algeria. Various heating and cooling of building applications and agricultural process applications have been discussed and proposed with Kuwait, Saudi Arabia, Iran, Korea, and the Philippines. It is expected that 2-3 of these agreements will be negotiated and operative by the end of calendar year 1976.

Most of the international aspects of Georgia Tech's solar energy program, other than the cited French and Italian efforts, are under the general coordination of the authors.

CONCLUSION—Georgia Tech is engaged in a multi-million dollar solar energy research program which spans all aspects of solar energy from low temperature applications in agriculture through building heating and cooling, industrial process heat, and high temperature power generation. More than 50 researchers are involved in these programs and more than 20 different externally funded projects have been undertaken within the last 3 yr. Efforts are now underway to expand the international activities in solar energy research and to continue and expand the extensive programs already underway.

ACKNOWLEDGMENT—The authors have taken material from write-ups describing many of the projects listed herein that was composed by some of the principal research participants listed in the different sections of this article. Without their efforts and assistance, such an overview of Georgia Tech solar energy programs would not be possible. Even those listed represent a limited portion of our entire solar energy research team.

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Engineering Sciences

SOLUBILITY STUDIES OF REFRIGERANT—CARRIER FLUID PAIRS FOR SOLAR POWERED AIR CONDITIONING APPLICATIONS

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ABSTRACT: *An experimental investigation of 16 different refrigerant-absorbent fluid pairs has been carried out in order to determine their suitability as the working fluid in a solar powered absorption cycle air conditioner. Criteria used in the initial selection of a refrigerant-absorbent pair included: High affinity (large negative deviation from Raoult's Law), high solubility, low specific heat, low viscosity, stability, corrosing, safety and cost. For practical solar considerations of a fluid pair, refrigerants were selected with low boiling points whereas absorbent fluids were selected with a boiling point considerably above that of the refrigerant. These additional restrictions are determined by the operating temperatures of the absorber and the generator of an absorption cycle air conditioning system. These temperatures were specified as 100°F (39°C) and 170°F (77°C). Data are presented for a few selected pressures at the specified absorber and generator temperatures.*

CONSIDERABLE work has been done in the past toward adapting absorption-cycle air conditioners to operate directly from solar energy. The results of some of these experiments have been reported by Curran (1975); Iachetta (1974); Semmens, Wilbur, and Puff (1974); and NASA (1974). To date, the ammonia-water system and the lithium bromide-water system, have been operated successfully from solar collectors although the results have been less than spectacular. Ammonia and water systems operate with a lower coefficient of performance than that of lithium bromide systems. The operational pressures are greater in ammonia systems and as a result will require greater pumping power. In addition, ammonia is a Class 2 refrigerant and cannot be installed in building air-handling systems.

Semmens, et al. and Chung, et al. (1963) indicate that lithium bromide-water systems tend to crystallize at high salt concentrations, and operate at about 50% cooling capacity with reduced dehumidification capacities at generator temperatures around 180°F (82°C). At these low generator temperatures (which represent the upper limit of flat plate collectors unless expensive selective coatings are used) cooling water is required for commercially available units, as opposed to the more desirable air cooled units for residential applications.

As a result of the current limitations on the ammonia-water systems and the lithium bromide-water systems, a research program was initiated to identify possible alternate working fluids for solar air conditioning applications. The goal of the program was to find the "ideal" refrigerant-absorbent pair which could be utilized in an air-cooled unit, and at the same time operate at the lower generator temperatures without reducing the cooling or dehumidification capacities.

SELECTION OF REFRIGERANT-ABSORBENT FLUID CANDIDATES—The criteria used in the initial selection of a refrigerant-absorbent pair were high affinity (large negative deviation from Raoult's Law), high solubility, low specific heat, low viscosity, stability, corrosion, safety and cost. For solar applications, refrigerants were selected with low boiling points and absorbent fluids were selected with a boiling point considerably higher than the refrigerant fluid. Approximately 10,000 fluids were evaluated relative to the specified criteria. The Refrigerant-absorbent fluid pairs which survived the evaluation process are given in Table 1. The absorber and generator pressures shown in Table 1 are respectively the nominal operating pressures of the evaporator and condenser of a conventional absorption cycle air-conditioning system.

In assessing a refrigerant-absorbent pair as a possible candidate, the solubility of the refrigerant in the absorbent is an extremely critical property. If one constructs an absorption cycle on an enthalpy-concentration diagram for a particular fluid pair, it becomes obvious that the coefficient of performance of the cycle is proportional to the concentration span. That is, the concentration of the refrigerant in the absorbent at the absorber conditions must be greater than the concentration of the refrigerant in the absorbent at the generator conditions. For the fluid pairs selected, the solubility of the refrigerant in the absorbent was not available at the specified thermodynamic conditions of the absorber and the generator. Experimental work and the results presented in this paper are concerned with the measurement of the solubility of the selected fluid pairs. For the experiments, the specified thermodynamic conditions for the absorber and generator are given in Table 1. The conditions in Table 1 were specified by the Chrysler Corporation, Space Systems Division, a prime contractor for the National Aeronautics and Space Administration for the development of a solar powered residential air conditioner.

SOLUBILITY EXPERIMENTS FOR PURE SOLVENTS—The solubility apparatus used in the experiments is shown schematically in Fig. 1. For the fluid pairs involving the salt solutions the apparatus and procedures were modified slightly to accomplish the specified objective. The discussion which follows immediately describes the experimental apparatus and procedure used to determine the solubility of a single component gas in a pure liquid. The case of the dissolved salt systems will be discussed in a separate section. The apparatus was designed to facilitate changes which could be anticipated in the course of testing a variety of refrigerant-absorbent fluid pairs.

To obtain a small sample of refrigerant from the refrigerant supply the total system was evacuated to less than 10 microns of mercury. The refrigerant supply valve was then opened to allow a quantity of the refrigerant to be transferred to

TABLE 1. Refrigerant-absorbent candidates and test parameters.

Fluid Pair Code No.	Refrigerant	Absorbent	Absorber Conditions 100°F (39°C) Pressure (psia)	Generator Conditions 170°F (77°C) Pressure (psia)
1A	Methylene Chloride	DME-TEG	4.03	15.75
1B	Methylene Chloride	Diethylene Glycol	4.03	15.75
2A	Refrigerant 114	DEM-TEG	16.90	52.50
3A	Ethyl Chloride	DME-TEG	12.37	39.60
4A	Methyl Chloride	Water	47.57	128.00
4B	Methyl Chloride	Diethylene Glycol	47.57	128.00
5A	Methanol	Water	0.90	5.40
5B	Methanol	Diethylene Glycol	0.90	5.40
5C	Methanol	DME-TEG	0.90	5.40
6A	Ethanol	Water	0.41	2.90
6B	Ethanol	Diethylene Glycol	0.41	2.90
6C	Ethanol	DME-TEG	0.41	2.90
7A	Water	DME-TEG	0.15	1.22
7B	Water	Calcium Nitrate	0.15	1.22
7C	Water	Lithium Bromide- Propylene Glycol (4.2/1.0 by weight)	0.15	1.22
7D	Water	Lithium Bromide- Lithium Chloride 4:1 Molal)	0.15	1.22

the refrigerant cylinder. This was accomplished by placing the refrigerant cylinder into a liquid nitrogen supply. After condensing an unknown amount of refrigerant in the cylinder the valve was closed and the vessel weighed.

A known amount of absorbent fluid was transferred to the absorbent container and placed into a constant temperature bath and connected to the gas manifold system. The total manifold system was evacuated and then the refrigerant cylinder valve was opened to allow the refrigerant to flow into the absorbent container. Mechanical agitation was applied to the mixture until an equilibrium pressure was reached. The solvent valve on the absorbent cylinder was then closed and the excess refrigerant in the gas manifold was condensed back into the refrigerant cylinder by chilling it with liquid nitrogen. The valve on the refrigerant cylinder was then closed and the refrigerant cylinder vessel weighed again. The loss in weight represents the amount of refrigerant absorbed in the absorbent fluid plus the small amount in the dead space above solution and minute residual amounts in the gas manifold system.

The absorbent vessel and the refrigerant cylinder each had a total volume of 30cc. The gas manifold was constructed of 1/4 in copper tubing and connected to the pressure gauges via the valves, refrigerant supply, refrigerant container, absorbent container, solvent vessel, vacuum line and transducer line. The 0-100 psig and 0-400 pressure gauges were used for initial pressure measurements above 15 psia. A 0-15 psia Statham transducer was used for all measurements below atmospheric. A 0-100 psig Stratham transducer was used for pressure mea-

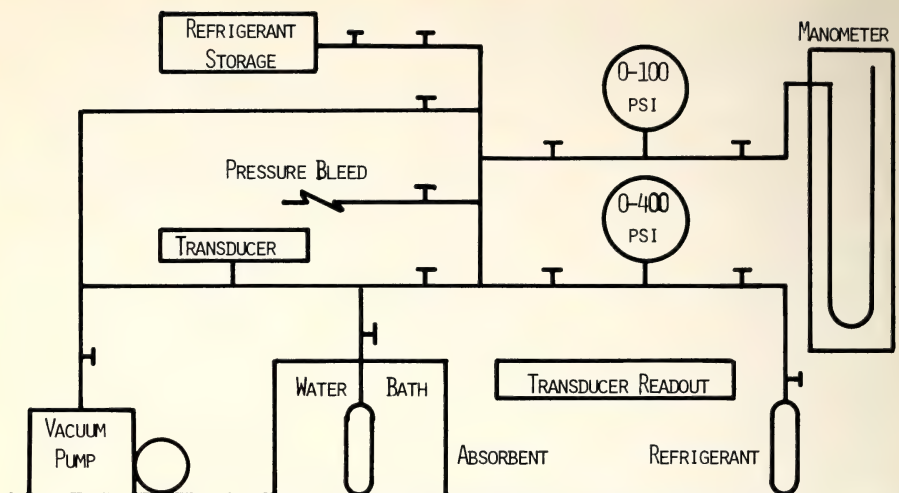


Fig. 1. Schematic diagram of experimental apparatus used in solubility studies.

surements made at the higher temperatures. The transducer measurements were read out on a BLH transducer conditioner and readout unit.

The 0-100 psig and 0-400 psig gauges were calibrated using a dead weight tester. These gauges were found to be accurate to within ± 0.1 psia. The 0-15 psia Statham transducer was calibrated against a mercury manometer and calibration curves were constructed with the digital readout as the ordinate and pressure as the abscissa. This permitted the determination of pressure to within ± 0.025 psi.

The mercury manometer was initially used for pressure measurements below atmospheric. However, ethyl chloride was found to be soluble in mercury resulting in the removal of the manometer from the system for pressure measurements.

The absorbent vessel was immersed in a Thelco Model 83 constant temperature bath. A mercury thermometer was used for measuring the temperature. The bath is fitted with a controller which maintains the temperature to within $\pm 1^\circ\text{C}$.

To determine the solubility as accurately as possible corrections had to be applied to the raw-weight data. These corrections consisted of (1) weight of refrigerant in the dead space above solution in the absorbent vessel and (2) weight of residual refrigerant in the gas manifold system after condensing the excess refrigerant back into the cylinder by chilling with liquid nitrogen.

To minimize errors in the pressure measurements, the barometric pressure was read periodically during the time the solubility measurements were being made. The variation in barometric pressure during a given day never exceeded ± 0.1 psi. The magnitude of this error contributes a negligible error in the determination of the solubility of the refrigerant.

The correction factor for the weight of refrigerant above solution and the residual refrigerant gas in the manifold piping were calculated assuming the gas obeyed the perfect gas law. The gas volume above solution was determined by two methods (1) calculating the volume of the absorbent in the evacuated absorbent vessel volume and (2) making blank runs with known amounts of absorbent in the solvent container and using air as the refrigerant gas. Since air is essentially insoluble in the absorbents utilized, both of these methods gave similar results. As a secondary check, a few selected material balances were made by weighing the absorbent vessel before and after introduction of the refrigerant gas. The sum of the final weight (refrigerant + absorbent) minus the losses calculated should equal the sum of the original weights of refrigerant plus absorbent. The material balance was within $\pm .02$ g out of a total of .5-2.5 g of refrigerant absorbed by 3-5 g of absorbent. To further validate the measurements, periodic checks of the system were made to insure the system was leak free.

To check out the experimental apparatus and techniques used to determine the solubility of a given refrigerant-absorbent pair, the published data of S.V.R. Mastrangelo (1959) for the Freon-22 and diethyl-ether of tetraethylene glycol (DME-TEG) fluid pair was used as a standard of comparison against this published data as shown in Fig. 2. From Fig. 2, it can be seen that when the excess refrigerant in the manifold piping was condensed back into refrigerant cylinder the data obtained agreed very well with published data mentioned previously. Even without condensing, data obtained agreed reasonably well within the published data from Mastrangelo (1959).

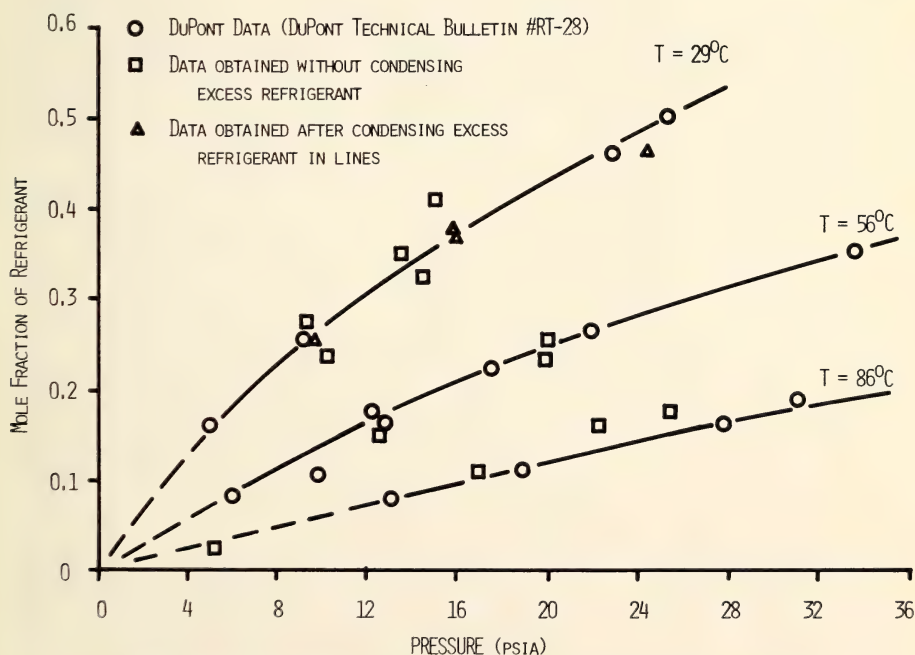


Fig. 2. System calibration data using DuPont refrigerant-22 data as a reference.

SOLUBILITY EXPERIMENT FOR LIQUID-SALT SOLUTION—The solubility of water (refrigerant) in various salt-liquid solutions (absorbent) was also investigated for various water-absorbent pairs. To determine the solubility of the water refrigerant in a liquid salt solution the experimental procedure was slightly modified. A solution of refrigerant-absorbent was established in equilibrium with the refrigerant vapor at the specified absorber conditions in the absorbent vessel. Heat was then applied to the absorbent vessel by immersing it in a second water bath fixed at the specified generator temperature of 170°. The pressure of the vapor above solution was monitored until a new equilibrium point was established at this new temperature. The new concentration of the refrigerant in the solution was then determined by calculating the amount of refrigerant which was boiled off as a result of the increased temperature.

An alternate method was also used which was similar to the procedure followed for the other refrigerants. A known concentration of the salt-liquid solution was placed in the absorbent vessel and additional water vapor refrigerant added until equilibrium was established at the specified absorber temperature and pressure. The concentration of refrigerant in solution was then calculated by the technique discussed previously for pure substances.

To ensure the procedure utilized for the salt solutions was providing valid results water-lithium bromide solutions were used as a standard of comparison. The data obtained from the water-lithium bromide solutions were within $\pm 3.6\%$ of data published in the literature for such solutions. In addition, several runs were made with each water-salt solution pair and the results were reproducible within ± 0.1 psia.

RESULTS AND CONCLUSIONS—Solubility of 16 different refrigerant-absorbent pairs were measured over a range of specified pressures and temperatures. The thermodynamic test conditions were fixed by the specified operating temperatures and pressure for the absorber and generator of an absorption-cycle air conditioning system. The results of the experiments are given in Table 2.

As one can see from the data presented in Table 2, many of the fluid pairs have higher solubilities at the absorber conditions than at the generator temperatures. Additionally, many of the fluid pairs have very low solubilities at the absorber conditions. In each of these cases, the fluid pairs are not suitable for absorption cycle systems at the specified conditions. However, two fluid pairs appear to hold some promise and warrant further studies at higher generator temperatures. These fluids are the methylene chloride/DME-TEG pair and the ethyl chloride/DME-TEG pair. Since in general the solubility of a gas in a liquid decreases with temperature and increases with pressure further experimental work is necessary to better clarify the suitability of these fluid pairs for solar air-conditioning applications. Additional work is being pursued to uncover other fluid pairs which appear to be suitable for absorption cycle systems at temperatures below 200°F (93°C). However, the results of these experiments indicate that the lithium bromide-water system is superior to other fluid pairs for solar absorption air conditioning applications at current temperatures accessible by flat-plate collectors without selective coatings.

TABLE 2. Solubility data for selected refrigerant-absorbent pairs.

Refrigerant-Absorbent Pair	Temperature °F(°C)	Pressure psia	Solubility Mole/Mole
1A	100 (39)	3.3	0.49
1A	100 (39)	7.7	0.66
1B	100 (39)	3.5	0.10
1B	100 (39)	4.4	0.13
1A	170 (77)	12.0	0.53
1A	170 (77)	15.8	0.67
1B	170 (77)	16.2	0.19
1B	170 (77)	16.3	0.23
2A	100 (39)	14.4	0.11
2A	100 (39)	17.0	0.14
2A	100 (39)	21.3	0.18
2A	170 (77)	35.7	0.09
2A	170 (77)	45.8	0.17
2A	170 (77)	50.8	0.19
4A	100 (39)	57.8	0.005
4B	100 (39)	54.8	0.18
3A	100 (39)	7.6	0.26
3A	100 (39)	9.3	0.27
3A	100 (39)	12.3	0.50
3A	170 (77)	37.8	0.45
3A	170 (77)	39.8	0.49
5A	100 (39)	0.9	0.001
5A	100 (39)	1.35	0.04
5B	100 (39)	0.9	0.21
5B	100 (39)	0.8	0.13
5C	100 (39)	0.9	0.15
6A	Absorbent (water) will vaporize at absorber conditions since $P_{\text{sat. water}} > P_{\text{sat. Ethanol}}$		
6B	100 (39)	0.4	0.004
6C	100 (39)	0.9	0.04
7A	100 (39)	1.0	0.36
7B	100 (39)	0.15	0.26 ¹
7B	175 (80)	1.05	0.25 ¹
7C	100 (39)	0.15	0.25 ¹
7C	175 (80)	0.80	0.25 ¹
7D	100 (39)	0.15	0.39 ¹
7D	175 (80)	0.52	0.38 ¹

¹Solubility fractions for these solutions are given as the ratio of weight of refrigerant (water) to total weight of solution at the specified temperature and pressure.

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LITERATURE CITED

- CHUNG, R., J. A. DUFFIE AND G. O. G. LOF. 1963. A study of a solar air conditioner. *Mechanical Engineering* 85(31):32-35.
- CURRAN, H. M. 1975. Assessment of Solar-Powered Cooling Building. ERDA Technical Report NSF-Fa-N-75-012. Washington.
- IACHETTA, F. (ed). 1974. Proceedings of the Workshop on Solar Heating and Cooling of Buildings. NSF-RA-N-74-126. Washington.

- MASTRANGELO, S. V. R. 1959. Solubility of Some Chlorflouro-hydrocarbons in Tetraethylene Glycol Dimethyl Ether, DuPont Tech. Rep. RT 28, E. I. Dupont DeNemours and Co. Wilmington, Delaware.
- NASA. 1974. Solar Residential Heating and Cooling System Development Test Program. NASA TMX-64924. George C. Marshall Space Flight Center.
- SEMMENS, M. F., P. J. WILBUR AND W. S. PUFF. 1974. Liquid Refrigerant Storage in Absorption Air Conditioners. Pap. No. 74-WA/HT-19. ASME Winter Ann. Mt. New York.

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CITATION FOR ROBERT NATHAN GINSBURG

Outstanding Scientist of Florida

March 19, 1976

WHETHER the need is to establish a new island laboratory, to develop an undergraduate or graduate curriculum, to lead research for a petroleum company, to organize an international conference or field trip for professional geologists, to edit a professional publication, or to discover connections between modern algal structures and ancient stromatolites, if geological sedimentation is the concern, the man to do it is Dr. Ginsburg.

Although he was born on the plains of Texas, and acquired B.A., M.A., and Ph.D. degrees at the University of Illinois and the University of Chicago, his professional career has largely been concentrated on the coasts and waters surrounding the State of Florida. He became a Research Assistant at the University of Miami Marine Laboratory as soon as he received his Master's degree in 1950. Then began his studies of carbonate sediments, shoaling-upward cycles of sediments, and the roles of organisms in diagenesis and intertidal erosion.

From 1954 to 1965 Dr. Ginsburg conducted his studies as a Research Geologist in the Exploration and Production Division of Shell Development Company, bestowing special interest on the oolitic sands of the Bahamas. In this capacity he was also responsible for training programs for many hundreds of petroleum geologists. A stint as professor of Geology and Oceanography at the Johns Hopkins University from 1965 to 1970 found him organizing another research program in the Bahamas, giving attention to sub-sea cementation in the Bermuda reefs, and heading an annual six-week summer seminar on Organism-Sediment Relationships at the Bermuda Biological Station.

In 1970 Dr. Ginsburg returned to the University of Miami as Professor of Sedimentology, Rosenstiel School of Marine and Atmospheric Science in the Division of Marine Geology and Geophysics. In this capacity he has designed, equipped and staffed the new Fisher Island T. Wayland Vaughan Laboratory for Comparative Sedimentology with the support of the National Science Foundation and most of the major oil companies, while extending his personal research on sedimentation to various parts of the earth.

In addition to delivering numerous invited lectures, teaching and directing the research of many graduate students, organizing, participating in and editing the proceedings of innumerable national and international conferences and field trips, serving as consultant to many oil companies, the State of Florida, and the National Science Foundation, Dr. Ginsburg has been Associate Editor of Marine Geology and has been Associate Editor of the Journal of Sedimentary Petrology since 1961, was co-founder of the Miami Geological Society, and has been President of the Society of Economic Paleontologists and Mineralogists.

The Florida Academy of Sciences takes great pleasure and satisfaction in awarding its 1976 Medal to the authority on sedimentology, DR. ROBERT NATHAN GINSBURG.

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